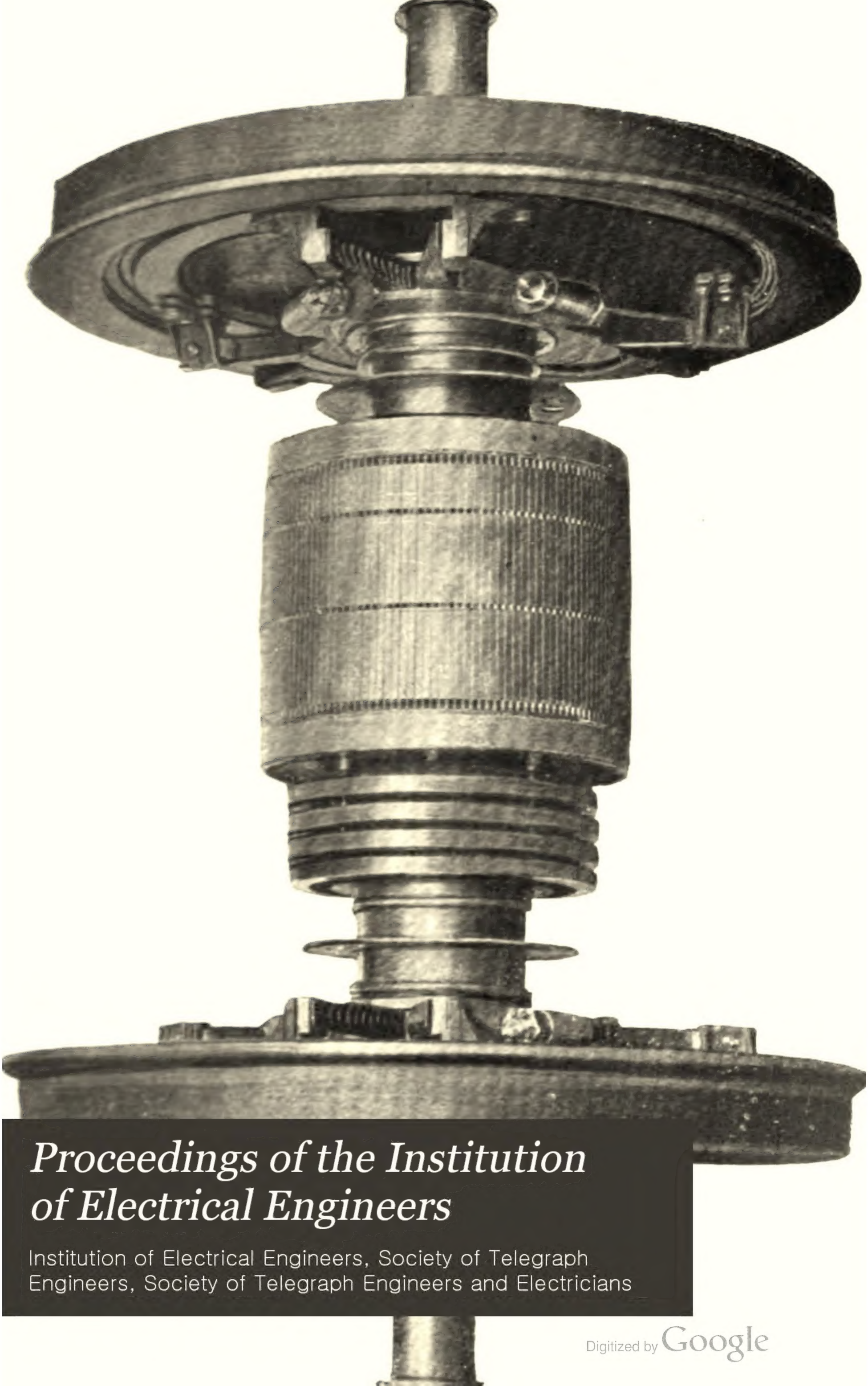

Proceedings of the Institution of Electrical Engineers

Institution of Electrical Engineers, Society of Telegraph Engineers, Society of Telegraph Engineers and Electricians

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

INCLUDING

ORIGINAL COMMUNICATIONS ON TELEGRAPHY AND ELECTRICAL SCIENCE.

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JOURNAL

OF THE

Institution of Electrical Engineers.

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An Extraordinary General Meeting of the Institution, being also a meeting of Section IX. of the International Engineering Congress, Glasgow, 1901, was held in the Natural Philosophy Theatre of the University of Glasgow on the mornings of Tuesday, September 3rd, Wednesday, September 4th, and Thursday, September 5th, 1901, Mr. W. LANGDON, President of the Institution, and Chairman of Section IX. of the Congress, in the Chair.

MEETING OF TUESDAY, SEPTEMBER 3rd.

The PRESIDENT: Gentlemen, I have much pleasure in meeting you here in Glasgow. I hope your visit may be attended with fine weather, and that it may prove in every way agreeable to you. Having regard to the fact that our time will be very much occupied, I have thought it better that we should not on this occasion read the minutes of the last meeting, which was, of course, the Annual General Meeting, and would consequently occupy much time; but I will ask the Secretary to read the Minute of the Council of October 18th authorising the Institution to take charge of Section IX. of the International Engineering Congress.

The SECRETARY read the Minute, which was as follows:—

"A letter was read from the Secretary of the International Engineering Congress, Glasgow, 1901, inviting the Institution to take charge of the arrangements for the work of the Electrical Section; and it was thereupon agreed that, subject to details being subsequently arranged, the Institution should take charge of the section as requested."

INTRODUCTORY ADDRESS TO THE ELECTRICAL SECTION (SECTION IX.) OF THE INTERNATIONAL ENGINEERING CONGRESS, GLASGOW, 1901,

By the Chairman of the Section, W. LANGDON, President of the Institution of Electrical Engineers.

Inasmuch as, within a very short time, it will be my privilege to deliver before the members of the Institution of Electrical Engineers my inaugural address, it was not my intention on this occasion to have encroached upon your time by anything in the shape of an address; but other Sections of the Congress having elected to follow that course, I fear I may be thought wanting in courtesy if I fail to comply with that which has proved so generally acceptable with others. I therefore propose to approach you, very shortly, upon a subject which, at the present juncture, I feel to be one of the highest importance.

Just fifty years since London, under the auspices of the nation's lamented Prince Albert, gave birth to the first International Exhibition. Followed by numerous others, at home and abroad, none, it is pleasing to note, have proved more successful financially, or more fully met the object for which they were established, than those inaugurated by the enterprise of Glasgow's citizens—the last and most successful of which forms one of the attractions incidental to the assemblage of this Congress and of the inauguration of the new century.

There can be no question that the result of these great undertakings has been for good; that they have been a stimulus to manufacture and trade; and that—greatly beyond all else—they have been a means making for peace. Whether we, as a nation, have been the gainer or the loser, the world has richly reaped. Exhibitions, railways, steamboats, education, the ready intercourse between peoples, have told, and are daily telling their tale. Few articles remain the privileged product of any one place.

Manufacture has become cosmopolitan, and the rivalry of the future between the most advanced nations of the earth will be that of manufacture—the power to apply the

products of the earth to the exigencies of life at the least cost, and with the least loss of time.

The supremacy of a nation may be attained by force of arms, but war cannot be carried on without the sinews of war, and the sinews of war means the wealth of the nation. Whence comes this national wealth? Surely by the industry and intelligence of its people—the power to observe, to apply, and to produce.

Lord Rosebery, when speaking recently at the Mansion House, remarked "we are coming to a time of stress and competition, for which it is necessary that we should be prepared," and later on he observes, "It is necessary for a nation in these days to train itself by every valuable method to meet the stress and the competition that is before us."

The question whether England, in comparison with other nations, is becoming retrograde in her industrial achievements must prove one of peculiar interest to all who seek this country's welfare. There are grave reasons to fear that in some paths, especially in the more modern applications of science, and notably in that development with which this Institution is so closely allied, we have not retained that prominent position which has characterised this country for so long a period.

Twenty years back, British manufacture stood on level ground with other countries in the production of electrical machinery, yet, if we may judge by the following figures, for which I am indebted to Mr. Philip Dawson, Member of this Institution, it would appear that we have from some cause failed to meet even our home demands. From these figures, which are approximate, it appears that of some 300,000 indicated horse-power of steam engines laid down for lighting and traction, 73,000 have been imported from the United States of America; and that, of some 200,000 kilowatt capacity of generators, 71,000 were derived from the same source. It will be understood that this does not mean that the residue was British production.

It is not my intention, nor would the time at my disposal admit of my attempting to enter into details why this is so. I take the bald fact as illustrated by the figures I have quoted. England did not meet the demand! Can it be that the British manufacturer lacked confidence in the permanency of this new electrical development? I quote

again from Mr. Dawson. The capital invested in European countries and the United States in electric lighting, power, and traction works, amounts to £367,000,000. Of this sum the United States contributes £200,000,000 and Great Britain £35,000,000. The number of miles of single track equipped for electric traction in the two countries is, relatively, 21,000 and 900. Of motor cars, 68,000 and 2,600. Germany, where the power employed for lighting work approaches closely that of England, has 2,300 miles of track, and 5,400 cars, although the invested capital is but twenty-nine millions, as against England's thirty-five millions for an enormously less mileage and smaller equipment.

The population of Great Britain is approximately 40,000,000 as against 70,000,000, that of the United States. The area in square miles is, relatively, 121,115, and 3,581,885. Too much stress must not be laid upon territorial comparison, although it would seem an evident corollary that the more dense the population the greater must be the demand for means of locomotion.

These figures should, at all events, prove effectual in disposing of any doubt that electrical development is stable. That it is only at the beginning of its era, and that an enormous field lies before it in almost every path of commercial and social life, must be evident to every observant person. It is not, however, with its utility that I desire to deal so much as with the means for its production: the production by our own country of all that is needed to meet not merely the wants of our home demand but that of our colonies as well.

Two important factors—cost and promptitude of delivery—attend successful competition in manufacture. Inspired with confidence in the future of electrical work, with, as it were, a prescience of those demands which must arise, and unincumbered with many of those restrictions and regulations which attend similar undertakings in England, other nations have seen and have seized their opportunity, gained experience, standardised their productions, and have thus, in advance of this country, prepared to meet any ordinary demand that may arise.

Cost depends much upon our labour conditions. Within a very short period rivalry in manufacture will be far more acute than is even now the case, and in it labour

will play the chief part. America, as well as England, has her labour troubles. Trade Unions exist there as well as here, but the principles which govern them differ from those which prevail here. There the man works unrestricted, with all his might. Of what avail is education to the child if manhood fails to take full advantage of it? In the following comment of the *New York Sun* we have an expression of opinion that may well be laid to heart: "When the British workman is willing really to work for his wages, then, and not till then, Great Britain may hope to survive in the great revolution which has begun to sweep through the modern economic world. There is no indication that that willingness will be shown until the bitterness of dire adversity has wrung it from the misguided Labour Unions of Great Britain."

The artizan should not lose sight of the fact that this question of cost is one which affects the employé as well as the employer. In the long run the master may be thrust to the wall. He may spend his last penny in keeping his works going, but when he closes those works the workman's means of livelihood are also, so far as the industry there dealt with affects him, closed. Unhappily, identity of interest, so necessary to both master and man, is more frequently marked by its absence than its presence. Until the employé can be induced to recognise in a practical manner the fact that his employer's interest is also his interest, those labour regulations which have been fruitful of so much harm to the manufacturing interests of this country, and which must in the end prove disastrous to the workman, will continue. So long as the production of a certain commodity is peculiar to a given locality, the question of cost is not so material; but where its production is world-wide, labour conditions must subscribe to those obtaining elsewhere, otherwise the market for that commodity will be lost.

We are speedily approaching a condition in the industrial progress of the world that will test to the utmost, not merely our means of production and our skill, but our position as a nation; for the pre-eminence of a nation will in future be largely determined by its progress in manufacture, and from it mainly shall we have to look for the means by which the nation's power will be

maintained. A people may trade. Articles may be bought and sold, but food for the worker lies not there. The wealth of a land is to be found in that which it produces—whether from the soil or by the handicraft of its citizens.

In such a rivalry—however friendly and generous that rivalry may be—it behoves us to consider how our manufacturing industry is placed in relation to that of other countries with which we have to compete; whether the conditions of production—labour, legislative enactments, or other restrictions, are such as give our rivals an initial advantage. The question is one of unexampled importance. We see and feel that the manufacture of any one article is no longer the privilege of any one country. The ready means of intercourse between nations—the feverish haste to exploit that which is new—all tend towards the establishment of a common knowledge of the productions of the day. Certain advantages remain to the locality from which the natural product is derived, but if this is submerged—lost in other directions—lost, for instance, in the cost of production—wherein is that country the richer? We have seen that England, once the chief source of iron and steel rails, has in that industry met with serious rivalry. How long will our position in textile fabrics remain even as at present? Is it not time we should look within ourselves and ask, Why is this so? To what is it due? Are our means of production at fault; are they too costly, too much restricted; or where are we to look for the reason?

Gentlemen, I plead no excuse for having ventured to address you upon a subject which might, perhaps, more properly have been approached through the medium of some other branch of science, for the reason that it is one which so materially affects the future prosperity of this country, and amongst other industries none perhaps more so than that embracing electrical development, that I have felt impelled to avail myself of this opportunity to urge the importance of its consideration. We see other countries prepared and preparing to take advantage of every new development in industrial progress. We see vast sums of money embarked in it, and especially in the use and advancement of electricity in its various modes of application, and we see that here in England—the pioneer of

mechanical power and progress—we are indebted to a foreign source to meet a great portion of our wants. There is a cause, and if our country is to retain her rank as a nation it is necessary that this cause, whatever it may be, should be ascertained, and, if possible, removed ere it is too late. Are we sacrificing the substance for the shadow? Are we, in our recognition of the liberty of the subject, in making provision for his welfare, so handicapping the source of his livelihood as to reduce its power of affording him that support? Are we, on the other hand, fostering manufacture and that which leads to manufacture? We have sternly to face the fact that manufacture is daily becoming cosmopolitan: that the production of a land must form its staple source of revenue; and in this sense to emphasise the need to consider those liabilities to which the British manufacturer has, in relation to the conditions attaining in other countries, to subscribe. The subject is one which may, I humbly and earnestly submit, claim the most careful consideration of every branch of our Legislative Administration, our labour organizations, and of every citizen of the British Empire.

Professor M. MACLEAN: I ask you to accord our President, Mr. Langdon, your thanks for his excellent address. He has touched on very many interesting points worthy of our consideration, especially the relative manufacturing outputs of America, of Britain, and of Continental countries. He also referred to the labour question, one which is of great difficulty and of great importance. I do not propose in any way to criticise or to offer any remarks upon his address. I simply ask you to award him your hearty thanks.

I think I may take the liberty and opportunity, as Chairman of the Glasgow Local Section of the Institution, to offer this Section's heartiest welcome to the Institution. I am commissioned by my Committee to say that each individual of them will be most willing to offer any help to any member who wishes to visit the electrical exhibits in the Exhibition.

The vote of thanks was carried by acclamation.

The PRESIDENT: I am extremely obliged to you for the complimentary manner in which you have received my

address. Although it is not quite on a technical subject, it is on a subject of so much interest at the present moment that I felt I might digress from the regular path.

I have now, gentlemen, to call upon you to pass a vote of thanks to Professor Gray for the use of these rooms. Professor Gray has been so kind as to place at our disposal not only this lecture theatre, but also his own room, for use during the meetings of this Section. We are greatly indebted to him. I should also add that Professor Gray has very kindly expressed his willingness to show and to explain to members the use of the various highly interesting pieces of apparatus employed in this section of the University. I will ask you to express your thanks to Professor Gray in the usual manner.

The vote of thanks was carried by acclamation.

Professor A. GRAY: I should be glad if members of the Congress will come round and see the laboratory and apparatus. It is hardly necessary to remind members of this Section that there are many pieces of apparatus in the department which are historically interesting—for example, a series of instruments illustrating the evolution of Lord Kelvin's electrometers, the apparatus of Joule for the determination of the dynamical equivalent of heat, and many others. I am very much obliged to you for your vote of thanks.

The PRESIDENT: It was thought by the Council that it would be well if we were to anticipate the visit of members to the Exhibition by a paper calling attention to some of the most important exhibits in the Electrical branch, and we therefore communicated with Mr. Sayers, who most readily compiled exactly that which was required. I will now ask Mr. Sayers to be good enough to read his paper.

NOTES ON SOME OF THE CHIEF OBJECTS OF INTEREST TO ELECTRICAL ENGINEERS IN THE GLASGOW INTERNATIONAL EXHIBITION, 1901.

By W. B. Sayers, M.I.E.E.

I. *GENERATING AND TRANSFORMING PLANT AND INSTRUMENTS IN USE THEREWITH.*

The Generating Station of the Exhibition.

Mr. J. C. Ward, of the Corporation Electricity Department, has given the author the following account of the installation :—

"The plant in the Machinery Section constituting the generating station for the supply of electricity to the Exhibition on the 500-volt continuous-current three-wire system (250 volts aside) is situated at the south end of the machinery hall and consist of the following—

Six Water Tube Boilers :

Two of	1,000 I.H.P.	Babcock land type with chain grates.	
One of	800 „	„	Marine type hand-fired.
Two of	1,000 „	Stirling type, one with Vickers stokers and the other gas- or hand-fired.	
One of	600 „	Davey Paxman, with special super-heater.	

One of the Stirling boilers is fitted for either coal or gas firing, and at present is being gas-fired, the gas being supplied from a Mason's gas-producer situated at the back of the boiler-house. Weir and Worthington's pumps are feeding the boilers through Royal's and Berriman's heaters and Kennedy's water meters, the boiler steam-pressure being 175 lbs.

The Generating Sets are as follows :—

1.	Willans and Crompton	1,200	I.H.P. Engine,	Multipolar Generator compound,	1,350	amps. at	500 v.
2.	British Schuckert ...	„	„	„	„	„	„
3.	Robey & Mavor & Coulson	500	„	Multipolar shunt ...	700	„	„
4.	Davey Paxman & E.C.C.	500	„	„ compound	570	„	„

No.					
5. Belliss & Bruce Peebles	400 I.H.P.	Multipolar compound	380 amps.	at 500 v.
6. Ernest Scott & Mountain	250 „	„ shunt ...	760 „	250
7. Alley & Maclellan & Mavor & Coulson	400 „	„ „	680 „	„
8. Browett, Lindley & Ediswan	250 „	„ „	525 „	„
9. Cisson & Clark Chapman ...	150 „	Two-pole shunt ...	320 „	„
10. Robey, & Scott & Mountain... ...	150 „	Multipolar shunt ...	250 „	„
11. Ruston Procter ...	150 „	Two-pole compound	370 „	„
12. Robey, & Scott & Mountain... ...	150 „	Two-pole shunt ...	200 „	„

"A balancer capable of dealing with an out of balance of 100 amperes is also installed by Messrs. Bruce Peebles close to the main switch-board and balances on the three-wire system of distribution. All the generators are worked self-exciting and run as shunt machines, the shunt regulation being controlled at the main board. The Lancashire Dynamo and Motor Company are also supplying current to the main board from three-phase plant installed at their stand. A continuous-current generator capable of supplying 150 amperes at 500 volts is coupled to a three-phase synchronous motor which is supplied from a three-phase steam generator of 200 k.w. capacity made by Messrs. Hicks Hargreave. In starting up, the continuous-current generator is started as a motor from the main switch-board and runs the three-phase synchronous motor up to speed. This motor is then synchronised with the steam generator, and the continuous-current supply regulated by a shunt-resistance connected at the main switch-board.

"At the main switch-board there is telephone communication with all the sub-boards at the ends of the feeders, and the whole of the Exhibition lighting is thus controlled by the switch-board attendant at the main board."

In the Grounds.—The conductors for arc-lights were of aluminium.

Mr. Camillo Olivetti, of Ivrea, exhibited in operation in the dynamo-room a new form of DIRECT-READING RECORDING WATTMETER. It consists essentially of a reversible motor, the armature of which operates through screw and worm gear, the scale pointer for direct observation, and also a

stile on a revolving drum for recording. The measurement of power is made by two coils, one shunt, and the other carrying the main current, just as in a Siemens wattmeter. A contact-making lever attached to the movable coil stands clear between two contacts when the coil is in equilibrium, but movement to either side causes the motor to run one way or the other, while the screw mechanism also increases or reduces the tension of a spring which restores the balance of forces acting on the movable coil. The instrument thus records how much the spring has been extended to bring the movable coil into zero position.

Mr. Olivetti, to whom I am indebted for the description of his instrument, states that he has made considerable improvements on the one exhibited. He gives the self-induction as 0·008 henry. Current in moving coil 0·025 ampere. The power wasted in the fixed coil at the end of the scale is 20 watts, and that absorbed by the motor 24–30 watts. No iron is used in the measuring part. Mr. Olivetti states that by using a number of coils and coupling them up mechanically he can measure the energy of a three-phase circuit with one instrument.

Kelvin and James White showed the latest forms of KELVIN measuring instruments, and notably the latest form of "Feeder Log." This instrument indicates and records the voltage and current on a feeder. It has been very thoroughly worked out, especially with respect to the problem of facilitating the operation of changing the paper record sheets. The clocks operating the recording cylinders are driven by synchronised clock mechanism.

Fergusson.—Another notable thing on the switch-board was the Fergusson AUTOMATIC OVERLOAD SWITCHES. These have the special feature that if an excess current passes when the switch is put on, the switch blades come free of the handle and fly off. Also the arc on breaking is partly blown out by an air-draft produced by the switch itself, and partly cut in two, as it were, by an insulating vane which slides over one of the contact blocks.

PRIVATE EXHIBITS IN GROUP I.

The British Schuckert Company.—This company showed in operation TRANSFORMING PLANT: 500-volt continuous

to 10,000-volt three-phase, by means of rotary and static transformers. The three 10,000-volt circuits are interrupted by a Schuckert H.T. SWITCH, when about 5 amperes are flowing in each circuit. Five amperes represent about 80 k.w. Each switch unit consists of two terminals, each in the form of a wire frame, mounted so as to be in the same vertical plane. At the lower side the frames are about 3 inches apart, but the rising wires diverge from each other at an increasing rate. The circuit is opened by a switch-blade at the bottom of the frames, and the arc which is established is carried upwards between the diverging wires by the air-current, and so stretched out until it breaks. Switches for 100 amperes and for 30,000 volts are also shown.

Bruce Peebles & Co. exhibited a 250-k.w. GENERATOR in the generating section—coupled to a Belliss T.C.T. Engine; 380 revolutions, 480 volts, 400 amperes shunt; 550 volts, 450 amperes compound. The generator is stated to have a fixed lead for all loads up to 25 per cent. overload, and the set a combined efficiency of 87 per cent.

Hick, Hargreaves & Co., and the *Lancashire Dynamo and Motor Company, Limited.*—The stand is designed to represent a high-pressure transmission scheme generating current at 5,000 volts, and transmitting it direct to 5,000-volt three-phase synchronous motor, driving a 6-pole direct-current dynamo wound for 500 volts, running at 600 revolutions per minute, and supplying 150 amperes to the Exhibition mains. ALTERNATOR: This machine is 200-k.w. three-phase alternating, generating current at 5,000 volts between any of the three terminals, the armature coils are star-connected, the star-connection being earthed. The alternator is of the stationary armature and revolving-field type, the fields consisting of laminated poles bolted to a steel ring, which is shrunk on to the rim of the engine fly-wheel, and the winding is of copper strip wound on edge. The armature is built up of wrought-iron stampings with all the joints staggered, so as to avoid any loss of permeability. The slots are open so as to enable the armature coils to be wound on formers, then taped up and slipped into the slots, being retained in position by wooden wedges, driven into a dovetail opening in the side of the slot. The number of the poles is 40, and the periodicity 50, the machine running

at 150 revolutions per minute. Screw gear is provided to move the armature clear of the fly-wheel, leaving either the field or armature coils readily accessible. The armature is split on the horizontal diameter, so that the top half may be entirely removed by means of adjusting screws. The armature can be moved in either direction to centralise with the field. The exciter is driven by ropes from a pulley bolted on the fly-wheel boss, and is of their standard type fitted with a patent brush gear. Current is carried to the high-tension switch-pillar in a cast-iron case consisting of six double-break switches, two in each phase, and three high-tension fuses, one in each phase. The synchronising gear and high-tension ammeter and voltmeters are fixed on a marble switch-board panel. The ROTARY TRANSFORMER consists of a three-phase 500-volt synchronous motor, coupled to a 6-pole direct-current dynamo. The alternating-current motor is of the same general design as the large alternator, and is wound for the same pressure; no step-down transformer is used. The armature has a slotted core with open slots, and is of the drum type bar-wound. The switch-gear for the direct-current side of the rotary transformer is mounted on a marble panel, and consists of a double-pole switch, starting switch, an automatic circuit-breaker and shunt-regulating switch. The rotary can thus be started from the direct-current side and synchronised; then, on strengthening the field, the direct-current machine will supply current to the Exhibition mains.

Mather & Platt, Ltd. exhibited their 10-polar, 800-k.w. DYNAMO for Salford. The following information with regard to the machine has been given to me by Messrs. Mather & Platt:—Poles and shoes are cast in one, and are bolted to the ring after the field spools have been slipped over them. The armature core is built on a double spider on which half-coupling for bolting to engine fly-wheel is cast, so that no stress passes through the shaft. The winding is of ordinary parallel drum type. There are 600 bars in the commutator. The diameter of the armature is 8 ft. 6 in., and that of the commutator, 7 ft. 2 in.

Speed, 100 revs. per minute.

Output as shunt ..	480	volts	× 1,615	amperes	}	Normal loads.
„ „ compound	525	„	× 1,476	„	}	
„ „ „	525	„	× 1,845	„		Overload of 25 per cent.

Commercial efficiency stated to be 95·1 per cent.
Losses :—Hysteresis and eddies, 2·27 per cent.
C^2R .. .. 2·57 per cent.
Friction .. .. 0·15 per cent.
Temperature rise :—Not exceeds 60° F. after ten hours full-load run at either voltage.
Weights: Armature, 25 tons.
Magnets, 25 „

Mavor & Coulson, Ltd.—This firm's chief exhibit was the 350-k.w. slow-speed generator coupled direct to a Robey Engine in the generating section. This set is of special interest on account of the slow speed at which it is run. Mr. Mavor's belief is, I understand, that the increased durability and security obtained by running at such a slow speed is worth the additional first cost, and the additional space occupied. Messrs. Mavor & Coulson favoured me with the following particulars of this generator :—

Armature, 72 in. × 22 in.
Watts per square inch cooling surface in fields, 0·57.
C^2R loss in armature = 14,780 watts } Watts per square
Estimated core loss in armature = 6,700 watts } inch = 1·89.
Numbers of section in commutator = 832.
Peripheral speed of commutator = 1,360 ft. per second.
Current density in brushes (full load) = 29 amperes per square inch.

2. *GAS-, OIL-, AND COAL-DUST ENGINES.*

The British Westinghouse Company showed in operation a WESTINGHOUSE THREE-CYLINDER GAS ENGINE, 125 B.H.P., 260 revolutions, direct-connected to 75 k.w. generator, 125 volts. The three cylinders of the engine each work on the Otto cycle. The cranks are set at 120°, so there is an impulse every two-thirds revolution. The governing is effected by varying, not the quantity of the gas, but the quantity of mixture, which is always of the best proportions. Three 250-H.P. engines of this type are stated to be driving two-phase 60 periods alternators in parallel at Saltley with entire success. The plant is stated to consume 18 cubic feet of town gas per k.w. hour output. The current from the gas-driven dynamo is used to operate various machines in the pavilion, including the 325 k.w. generator set with Markham Cross Compound Engine. The generator of the set is wound for 500 volts, but it is driven as a motor up to within about 20 per cent. of its

normal speed with 125 volts current by reducing the magnet excitation.

Diesel Oil Engine.—A 20 B.H.P. DIESEL OIL ENGINE was shown in operation. This engine is of peculiar interest in that it has no special ignition apparatus. A charge of compressed air is further compressed by the returning piston to a pressure of between 500 to 600 lbs. per square inch. The high compression of the air raises its temperature sufficiently to ignite the oil and air spray, which is injected from the commencement of the out stroke for as long a period as the governor may determine. The combustion is thus much more gradual than in other oil and gas engines. The engine has been very favourably reported on by Professor Unwin in this country and Professor Meyer in Germany. According to the latter, the consumption of Baku oil in an engine of German manufacture, having a working stroke every two revolutions, was about 0·475 lbs. per brake horse-power hour.

The engine exhibited was manufactured by Messrs. Scott & Hodgson, of Guide Bridge, Manchester. It is of horizontal type and has a working stroke every revolution. The rated power is 22 brake horse-power; speed, 210 revolutions per minute.

The engine is started at once from cold. To accomplish this, one of the pump cylinders is transformed by suitable mechanism operated by a hand lever into an air-engine cylinder. A store of air at high pressure which has been drawn from the engine during previous working is used to give the engine a few turns, and when a certain speed is attained the oil supply is turned on to the working cylinder and the engine starts. The engine takes an impulse every revolution. There is a low-pressure pump in tandem with the working cylinder to blow through the latter, and two pumps for compressing air up to the necessary pressure for spraying the fuel into cylinder.

D. Stewart & Co. showed a MCCALLUM'S COAL-DUST BURNING ENGINE. 100 H.P., 150 revs. This engine has been built for a syndicate, and is in an experimental stage. It has been run for periods of half an hour or so light. The piston is of plunger form, so that there is no sliding on the surface of the cylinder, but only in a gland round the plunger. Above the gland is a sill of water or (and ?) oil

in which any burnt dust collects. The combustion is effected in a chamber adjoining the working cylinder. A plate of heated iron is thrust from a recess by an eccentric wheel and rod into this chamber, and at the same time enough coal-dust for one impulse is blown on to the plate at the time when the piston (plunger) is at the back end of its stroke, at which time the chamber is full of air which has been compressed by the returning plunger. Mr. McCallum states that the consumption of coal-dust is ½-lb. per I.H.P. in an engine of this size.

3. *ELECTRIC TRACTION.*

British Schuckert Co.—This firm exhibited a SURFACE CONTACT TRAM-CAR SYSTEM similar to that in operation at Munich. The road contacts are made alive in succession by automatic switches which are grouped in road boxes at intervals of about 120 yards. The switch units are provided with sliding contacts, and are held solely by contact spring clips. A switch unit can be pulled out and another pushed into its place. The act of pushing in makes all connections through the spring clips, and the switch is ready for work.

A feature of the system is that the car carries a trailing brush which connects the road contact to the rails just before it passes from under the car. Should the road contact be alive from any cause, the short circuit causes the section to be cut off by means of an overload switch.

They also showed ELECTRIC LOCOMOTIVES in operation. There were two: one to work off 250-volt overhead supply, the other carrying 39 accumulator cells of 66 ampere-hour capacity; the latter is stated to be adapted to haul ten tons at four or five miles per hour.

The British Westinghouse Company exhibited a RAILWAY CIRCUIT-BREAKER on switch-board. The current at which the circuit-breaker acts is readily adjusted by means of a sliding weight. On breaking circuit the arc is broken between two carbon blocks, which are carried on arms that reach above the board so that the flash is out of harm's way.

They also showed an ELECTRIC TRAM-CAR, fitted with Newell track brake. The magnets, in pulling towards the rails, also pull the shoe brake on to the wheel, increasing the

adhesion at the same time as the brake is applied. The brake is operated by the car motors run as generators.

The motors can be inspected from below the car, and are of 35 H.P. according to American rating, that is a rise of 50° C. at the end of one hour's run.

Dick Kerr & Co. showed a TRAMWAY GENERATOR by the English Electrical Manufacturing Company, Preston. 550 volts, 910 amperes, 90 revolutions per minute. The armature is designed to be pressed directly on the shaft of engine. The field poles are of laminated steel, cast into the cast-iron yoke. The armature bars are without joints except where they connect to the commutator. The machine is a duplicate of a number already in use. It is stated that, on actual test, the machine ran for ten hours at full load, and for two hours thereafter at 50 per cent. overload with a rise of temperature of 57° Fahr.

They also showed CONTROLLERS. One of those exhibited embodied a rheostatic electric brake operated by throwing the controlling handle in the opposite direction to that used in applying power.

4. *CONTROLLERS, STARTING SWITCHES AND STARTING RHEOSTATS.*

Lahmeyer & Co. showed a CONTROLLER FOR OVERHEAD TRAVELLERS. By an ingenious mechanical gear, two switches are operated in such a way as to produce cross and traversing motion at the same time by means of one handle, which has to be moved in a direction corresponding with the direction in which it is desired to move the traveller.

The Sturtevant Engineerng Company exhibited MOTOR STARTING SWITCHES. A starting switch was shown with time limit overload. The trigger magnet, which is in series with the main circuit, is shunted with an iron ribbon resistance. If the overload is not too great and does not last too long, the trigger does not act; but if the load is above normal and lasts too long, the ribbon becomes heated, and owing to its increased resistance, more current passes through the trigger coil and operates the trigger. A short circuit or excessive overload current operates the trigger immediately. They also showed a MULTIPOLE-SWITCH STARTING RHEOSTAT in operation, in which a number of separate switches, with

trigger arrangement that prevents them from being put on in the wrong order, are used in place of the usual sliding blade. They also had a SELF-STARTING SWITCH FOR MOTORS, shown in operation. It consists of a number of solenoids and contact switches which act in succession, when once started, by making a circuit through a small switch.

5. *SUNDRY APPLICATIONS OF ELECTRICITY.*

(*a*) **Clocks.**

Barr & Stroud showed an ELECTRIC CLOCK. The commutator of the transmitter is a novel and pretty device, as is also the ratchet mechanism of the electric clock; the latter forms an absolute locking ratchet and is, it is believed, the only one ever devised.

(*b*) **Drilling-Machines.**

Mather & Platt, Ltd., exhibited a DRILLING MACHINE WITH MAGNETIC ADHESIVE FOOT. The foot of the drill pedestal contains an exciting coil through which passes a central core, and over which the cup or bell-shaped foot extends. The central core and edge of the cup are planed off level, so that when set upon an iron surface the magnetic circuit through the coil is completed, and the foot adheres with a force of about three tons when the coil is excited. It is recommended to use dogs for heavy work, to prevent the drill foot from creeping.

(*c*) **Mining.**

The *British Schuckert Company* exhibited ELECTRIC HAULAGE for mining work. The rope drum is driven through a friction coupling consisting of two opposing discs, each fitted with projecting wires like brushes. If the cage should catch, the coupling slips and avoids breaking fuse. There is an automatic switching-off arrangement to avoid over-winding. They had also ROCK DRILLS in operation. For cutting hard stone the feed is caused by hydraulic pressure, and is not therefore at any given rate in proportion to the speed of the drill; on the other hand, the rate of cutting will be determined by the actual hardness of the stone being cut at the moment, and the highest practical rate of cutting can thus be attained without endangering the drill.

Clark, Stevenson & Co. had a COAL-CUTTING MACHINE with wheel cutter; traverses one yard per minute, and undercuts 3 ft. 6 in., taking 23 H.P. to drive.

Mavor & Coulson, Ltd., showed a HURD'S COAL-CUTTER. The bar cutter is drawn backwards and forwards whilst rotating—this causes it to clear itself of cuttings. The motor is 14 k.w. The coal-cutter will cut 110 yards 3 ft. 6 in. deep per four hours, which includes time in laying rails; time of actual cutting, 150 minutes. They also show a SHIP DECK PLANER, which does the work of seven men and requires two men to operate it. The motor is of 3 H.P.

(*d*) Motors.

Selig, Sonnenthal & Co. showed the Stow Manufacturing Company's MOTOR with flexible shaft. The speed of the motor can be varied 50 per cent. (it is stated) by withdrawing or converging the magnet poles or part of them.

(*e*) Overhead Conveyer.

Mather & Platt, Ltd., had an OVERHEAD CONVEYER for carrying goods or luggage in railway stations, etc. Lifts 20 cwt. at 26 ft. per minute, travels 700 ft. per minute; fitted with 2 B.H.P. motor. The current is carried by the rails, which are insulated from the columns.

(*f*) Printing.

The *Glasgow Herald* showed a HOE PRINTING PRESS ELECTRICALLY DRIVEN. The press is a four-roll one with two folders, with output of 48,000 copies of eight-page paper per hour, or 24,000 copies of sixteen-page paper. The electrical equipment is by the British Electric Plant Co., Ltd. The motor is rated at 50 H.P., wound for 500 volts and 400 revolutions. It is geared direct with steel gears into a spur wheel on the machine-driving shaft. The special features of the driving refer to the starting and the turning of the machine slowly forwards or backwards which is necessary in "making-ready." A motor-generator or "reducer" is used which takes in current at 500 volts and has an output capacity of 75 amperes at 75 volts, or between 5 and 6 k.w.

In starting the motors the sequence of operations is as follows:—

(1) Shunt of motor is excited off the 500-volt-supply.
(2) The motor-generator is started up.
(3) The 75-volt side of motor-generator is connected direct to motor brushes, and machine starts to run slowly.
(4) The 500-volt-supply with resistance in circuit is connected in parallel with motor-transformer on to motor brushes.
(5) The resistance in 500-volt-circuit is gradually cut out. When the speed of motor has increased sufficiently to cause the pressure at motor brushes to exceed 75 volts, the current from motor-generator falls to zero, and a minimum cut-out operates and breaks the 75-volt-circuit and also the 500-volt-supply to motor-generator, which therefore stops and leaves the main motor with more or less resistance in armature circuit on the 500-volt-supply.

The whole of the operations are performed by means of a single hand-wheel mounted on a screw which moves a traversing carriage. This carriage in its passage operates the several switches, and after the motor is started the continued movement cuts out the resistance. The machine can be stopped from a number of pushes fixed in convenient positions and from beside the main switch. The pressing of a push short-circuits the hold-on magnet of a fly-away switch. The motor armature is left coupled up with its field, and a brake—the weight of which is held in suspension while current is flowing to the motor—comes into operation and stops the machine. The main switch hand-wheel must be run back to the starting position before current can again be put on to the motor. The machine starts with about 40 amperes through the motor, takes about 65 amperes at half-speed, and 90 amperes at 21,000 copies of a sixteen-page paper per hour.

Mr. H. D. Robertson, manager of the *Herald*, and Mr. W. L. Spence, patentee of the arrangement, kindly arranged to be present to show the machine in operation.

(g) **Pumping.**

The *British Schuckert Company* had a PUMPING PLANT in

operation consisting of a direct-coupled, twin duplex pump to deliver 3,200 litres per minute against a head of 520 metres. The motor is a Schuckert standard, multipolar type, stated to be capable of developing 615 H.P. It is mounted between the two pumps, and is designed to run at 146 revolutions per minute for 10 ft. suction, or up to 165 for smaller suctions. The pumps are by Erhardt and Sehmer, and have concentric valves.

Mather & Platt, Ltd., had an ELECTRICALLY-DRIVEN FEED PUMP. The quantity of water delivered by the pump is controlled by varying the length of stroke of the plungers. The stroke is varied by moving the pin which drives the plungers on an axis which is eccentric with the axis of rotation; this is accomplished by mechanism operated through a hand-wheel.

Mavor & Coulson had a CENTRIFUGAL PUMP which, direct-coupled to 4 H.P. motor, throws 4,000 gallons per hour against 50 ft. head.

(*h*) Search Lights.

The *British Schuckert Company*, in their search-light tower, had a SEARCH-LIGHT LAMP, type 6,150, 5 ft. diameter, 150 amperes. The lantern is provided with two small motors, by means of which it may be operated systematically from below to sweep a given area. The 500-volt-supply current is reduced in a motor-transformer in the base of the tower.

6. *TELEPHONES.*

Telephone Switch-Board.

The *Glasgow Corporation* had a SWITCH-BOARD adapted for 400 metallic circuit lines, made by the Telegraph Manufacturing Company, Helsby, which is at present operating 969 subscribers and 15 junction lines. These lines are also fitted with test-jacks, lightning guards, and high-voltage guards. The system of switching is the "Bennett-M'Lean," which yields the same results as the call-wire system, but does not require a special call-wire, the subscriber's metallic loop being utilised from the call to the operator. This is managed by means of relays which are wound so that the armature remains unaffected when a current passes through the coils in series, but is actuated when a current is supplied between the two coils, splitting between them. A common

battery with one pole to earth is joined to a point between the coils, and the subscriber, when pressing a special key, brings this battery into operation, thereby holding down the armature. The armature is arranged to bring the operator's telephone into circuit when attracted, so that when a subscriber presses his key he is in communication with the operator, but when the key is unpressed the operator is cut off from the line, which is then available for talking to other subscribers. There is also exhibited an iron standard such as is used for overhead construction by the Corporation, fitted with "Bennett" channel-iron arms and "Bennett" insulators.

Specimens of the underground cable used by the Corporation, and manufactured by the British Insulated Wire Company, were also shown, together with a model of a steel terminal distributing pole. There are two call boxes attached to the exhibit from which communication can be had all over Great Britain and Ireland, by means of the Post Office trunk lines, as well as to all Corporation subscribers. Examples of the wall and table instruments used by the Corporation are also shown.

The *National Telephone Company* had an Exchange fitted up and working in the Exhibition, and with this exchange were connected 110 exhibitors' stances. The switch-board is fitted with the latest American device, whereby, when an exhibitor presses the key of his instrument, a lamp indicates at the switch-board that he is calling. An electric-motor generator, deriving its power from the electric light mains in the building, is provided at the switch-board for ringing purposes. Ample call office accommodation has been provided, and ten special boxes fitted up for the use of the casual caller. By payment of one penny per call, communication can be had with any one connected in the Company's Glasgow Exchange area. For the usual trunk charges communication may be had throughout the kingdom.

7. *MISCELLANEOUS.*

R. G. Ross & Sons showed Ross's Speed Reduction Gear. This is an ingenious type of sun and planet gear. It is very compact and quiet in working. Mr. Ross obtains practically any speed ratio with two pairs of gears and an

eccentric. He has supplied several sets to Guinness's Brewery in Dublin; these have a ratio of 6,133 to one. The efficiency of this gear is given in tests, copies of which have been supplied to me, at 87 per cent., but it is stated that it is often as high as 95 per cent., and I do not doubt that this is so.

The *British Westinghouse Company* showed EXPERIMENTS WITH REVOLVING FIELD (Two-phase). Iron discs were shown rotating in the neighbourhood of a ring in which a revolving field is generated by two-phase currents.

The PRESIDENT: I almost feel it unnecessary to call upon you to express your thanks to Mr. Sayers for his kindness in writing this paper, for you have, in fact, already done so by the manner in which you have received it. We thank Mr. Sayers for his very lucid paper; it will be of very much use to us, and still more so for reference when printed in the Proceedings of the Institution.

A vote of thanks to Mr. Sayers was passed by acclamation.

The PRESIDENT: With a view to assist you in visiting those points of most interest in the Exhibition alluded to by Mr. Sayers, it has been arranged, through the kindness of Mr. H. A. Mavor, who has taken a very great deal of interest in the subject, and who has been so good as to get together a band of gentlemen thoroughly acquainted with the exhibits who will act as guides, that on leaving this room those who desire to do so shall arrange themselves in groups and visit the Exhibition under the guidance of these gentlemen.

I should add that the exhibitors have promised to place their attendants on duty, so that in case questions are asked there shall be some one present to give the necessary information.

MEETING OF WEDNESDAY, SEPTEMBER 4th.

The PRESIDENT: I think it may perhaps facilitate our business if I announce at the present moment that it has been suggested and agreed to by authors of papers that their papers shall be read in abstract and not *in extenso*. The time at our disposal will not admit of our dealing with papers in full.

I have now the pleasure of introducing to you Herr

Lasche, the author of the paper on "High-speed Electrical Railway-Cars of the Allgemeine Elektricitäts Gesellschaft, Berlin." One great feature which will, I am sure, attract your attention in this paper is the enormous care taken by the Association for the study of Electrical High-speed Railways, the association which was formed for the purpose of investigating this matter, in order to arrive at a conclusion on many of those points which are so material to the definition of the question.

HIGH-SPEED RAILWAY-CAR OF THE ALLGEMEINE ELEKTRICITÄTS GESELLSCHAFT, BERLIN.

By O. LASCHE (Berlin).

The German "Association for the Study of Electrical High-speed Railways" (Studiengesellschaft für elektrische Schnellbahnen) has been formed with the object of gaining experimental knowledge of the electrical working of long-distance railways, and as to the construction of the cars, the consumption of power, and the wear and tear of the permanent way, as well as of the limits within which railways can be run by electricity on a sound, technical, and economical basis. The theoretical study of the question, and the experiments resulting therefrom, have, up to the present time, been of a general character only, and have had no reference to the planning of any special track. The first trials will be commenced shortly on the military railway from Berlin to Zossen, which the Imperial Military Railway Board of Administration has placed at the disposal of the Association.

A speed of 200 kilometres (124 miles) per hour has been assumed as the maximum for the present construction of car, but this does not imply either, on the one hand, that the main object of the experimental line will be the attainment of this speed, or, on the other hand, that there may not be a possibility of running at still higher velocities. The trial has for its special object the establishment of a sound basis for the projection, construction, and working of lines at the usual (or at higher) speeds. In certain technical journals and newspapers the attainment of a speed

of 200 kilometres per hour has been ridiculed as being impossible, whilst in others it has been repeatedly asserted that this speed can be attained by steam locomotives. Indeed, the Americans claim to be able to travel at still higher velocities; and it is much to be desired that efforts should still be made in this direction with steam railways. In view of the present requirements of traffic, efforts should, of course, be made to travel more quickly, but *special attention must be devoted to making travelling more convenient for the public;* and electric traction is the best for this purpose. Naturally, the object of the present experiments and of those conducted during the next few years will be to compare the economy of the electrical systems with those in which steam driving is employed, and to ascertain the *total* cost of each system when running at different speeds, and especially at the higher speeds. It must be remembered that money was not treated as the main consideration when electric light and electric power were introduced. Indeed, even at the present day electric light is often much more expensive than gaslight, and yet it is very extensively used. In the same way the electric working of railways is likely at first to be largely adopted in cases in which the higher cost (if, indeed, the cost should prove to be higher) may be disregarded on account of the greater convenience afforded by the system. In this way the introduction of electric long-distance traffic may be easily developed and universalised.

The ability to run separate motor-cars in rapid succession is a great advantage in favour of electric driving; and such a service of motor-cars has been proposed for use on suburban and long-distance lines. With this in view, the experimental cars of the Association have been built in the form of passenger-cars rather than as locomotives. This method of working with single cars, running without producing smoke and at short intervals, is already required by the public, and should therefore be remunerative. Another advantage attendant on electrical driving is that, on lines on which the traffic is increasing, the existing permanent way, bridges, etc., may be retained; because, in place of heavier locomotives and longer trains, light and separately running motor-cars will be used.

The permanent way and its maintenance are of course

very important considerations in connection with the electric system, and further considerable improvements are necessary; but the trials about to be made by the Association should show to what extent the wear produced by electric locomotives is less than that caused by steam locomotives.

The experiments will, it is hoped, establish a basis for the calculation of the working expenses of electric main lines, and also of the outputs of motors for the various speeds and of the increasing influence of air resistance, as well as for the determination of the size of power-stations necessary. The lower limit of speed at which electrical may be more economical than steam traction is about as little known as is the higher limit. All that is known is that, with steam locomotives, the consumption both of steam and (more especially) of coal is very greatly increased with increasing speed. But by centralising the generation of power the circumstances will of course be entirely different. Large steam engines of the best construction may then be used with boilers provided with super-heating and feed-water heating apparatus. This centralisation (and consequently the attainment of a practically uniform load) is now possible for very long distances. Three-phase alternating current can be generated at a pressure of 40,000 or 50,000 volts, so that electrical energy can now be transmitted for very great distances without serious loss; and all the railway lines over a large area can be supplied with current from a central station placed in a favourable situation.

Nature of Current Used.

As the problem to be solved is that of long-distance transmission, the current to be adopted should be three-phase alternating current of high voltage. For the experiments to be described a current of only 10,000–12,000 volts was necessary; it was supplied by the Oberspree Central Station of the Berliner Elektricitäts-Werke, the distance from the central station to the nearest point on the trolley wire being about 15 kilometres [9·3 miles]. At present, the current supplied to this wire is at a pressure of 10,000–12,000 volts, and the transformers are mounted in the car itself, a low voltage—435—being used for the motors. With regard to

future developments, it is still an open question whether it will be advisable to keep the heavy weight of the transformers within the car, or whether it may not be preferable to reduce the high pressure (about 50,000 volts) by transformers alongside the track, to a medium pressure of about 3,000 volts, and to wind the motors for this latter voltage.

The conversion of three-phase into continuous current is not practicable for the service of long-distance railways, because it requires the use of rotating machinery and consequently necessitates attendance, whilst transformers for varying the potential of three-phase current have no moving parts. Moreover, continuous current demands the employment of a very low voltage, and therefore of short distances between the transforming stations. It might, however, be necessary to use continuous current for long-distance cars while passing through a large town, the three overhead wires of the three-phase system being inconvenient for points and crossings ; a slow-speed locomotive could then be coupled temporarily in front of the car.

Investigations.

The problem set to the Allgemeine Elektricitäts-Gesellschaft was as follows :—To construct a motor-car to run at a speed of 200 kilometres per hour and to accommodate 50 persons. The car to have two bogies with three axles each, and the motors to be adapted for a total output of 1,100 H.P. normal and 3,000 H.P. maximum. The electric current provided to be three-phase at 12,000 volts, and at a frequency of 50 complete periods per second. The weight of the cars to be as small as possible, but on no account to exceed 8 tons per wheel ; and the shape to be such that the car is within the standard structure gauge necessary to allow it to pass over the lines of the State Railway.

In the first part of the present paper some of the preliminary experiments and investigations are described, as they are of special interest in view of the novelty of the whole system. The description of these investigations shows in the clearest possible way the results which it was sought to attain. The second part contains the description of the car and its electrical arrangement.

Although primarily experimental, the car was con-

structed to run permanently at any speed decided upon after the trials shall have been completed. It must not, of course, be compared with the ordinary tram-car or with the low-speed locomotive, for the motors, the transformers, and the starting and regulating apparatus are of an entirely new type.

In this paper an account is given of the attempts made to attain the lightest possible weight both for the car and for the electrical equipment, *i.e.*, transformers, motors, and apparatus (Section 1).

In view of the high speed desired, the Company thought it necessary to find means to relieve the axles from the heavy weight of the motors, or at least to prevent the axle from being directly burdened thereby (Section 2).

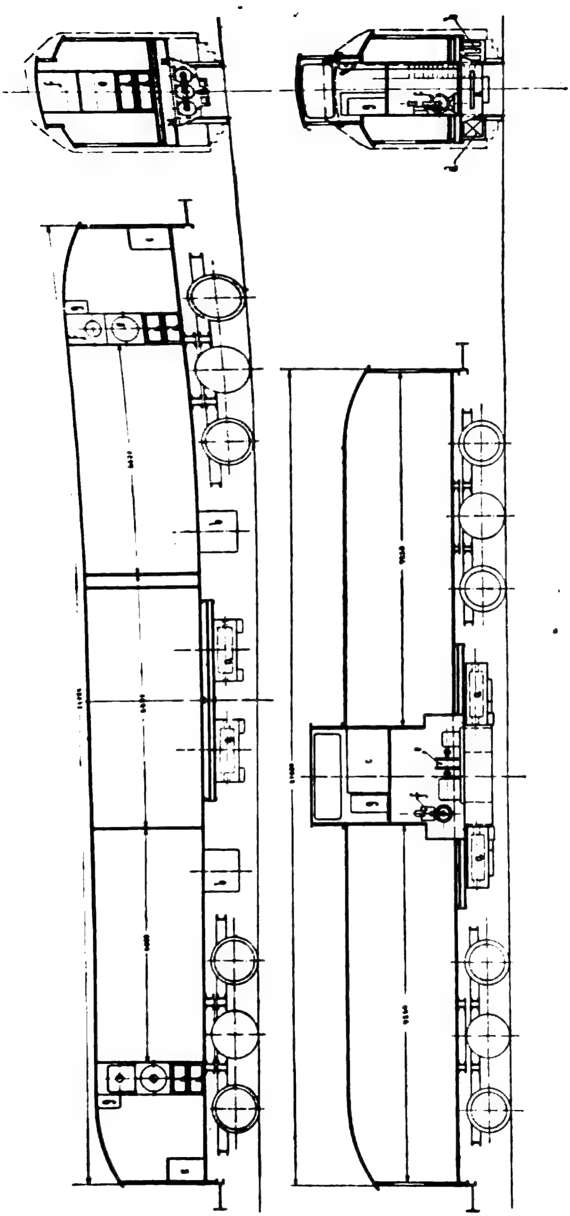
The starting and regulating apparatus for a 3,000-H.P. car could not be consfructed of the same type as that used for the ordinary controllers for cars requiring hardly 100 H.P. Experiments on a very large scale were therefore necessary in order to test the novel arrangements (Section 3).

Braking at a speed of 200 kilometres per hour (that is at a peripheral speed of 56 m. [184 ft.] per sec.) by means of friction brakes was found to be unsatisfactory, and it was therefore necessary to provide means for braking electrically (Section 4).

A large number of other new details had also to be designed. The motor bearings have to work at a surface speed of about 14 m. [46 ft.] per second, and the collecting rings of the armatures at a speed of about 40 m. [131 ft.]. The trolleys required special consideration, and presented one of the most difficult of the problems to be solved. The preliminary steps that were necessary in this connection are described in Section 5.

1.—Weight of the Electrical Equipment.

Figures 1, 2, and 3 show the changes made in the main design of the car, and especially in that of the body of the car at the beginning of the trials. At first, in view of the condition that the car must be able to run either forwards or backwards, it was proposed to construct a driver's platform, containing the necessary starting apparatus, at each end, the construction being such as to enable the driver to control



FIGS. 1 AND 2.

the whole car, including the motors of the rear bogie, by means of the front starting device. The arrangement of cables required for this purpose proved, however, to be impracticable for the 3,000 H.P. which was to be used. Matters were facilitated by having two separate electrical equipments, one for each bogie, and operating the rear starting device at a distance, either by means of an electro-motor, or by compressed air, or by water pressure, or the like.

Fig. 2 shows the two driver's platforms combined in one, with a single compartment for the apparatus, in which, however, the two circuits were kept separate. This compartment had two divisions, the lower for the necessary apparatus and machinery, and the upper for the driver and the starting and regulating apparatus. Although on account of the high speed, the observation and inspection of the last 30 metres of the track is impossible, the arrangement was again altered and the driver's platforms were placed at the two ends of the car. Efforts were made to leave the front and rear windows of the car unobscured for the benefit of the passengers, as a view in these directions is especially desired.

These three main conditions—the stationing of the driver at the front of the car, the placing of the apparatus in the position which calls for the shortest cable connections, and the devotion of every consideration to the comfort and safety of the passengers—led to the development of the last design, Fig. 3. The whole of the apparatus, cable, and safety devices are arranged in the middle compartment, which, with the transformers below it, is separated from the passenger-compartments by air shafts with double iron walls. The driver always stands at the front of the car, separated from the passengers, in a compartment in which there are no connections at high electrical pressure. The control is effected from the driver's platform by mechanical transmission.

It has already been stated that the transformers had to be mounted in the car itself, although they add much to the total weight of the car.

In making the calculations for the transformers and determining the cross-sections necessary for the iron, the question of the heating and cooling of the iron and of the copper coils is of the greatest importance. The cooling of the transformers by air taken from below the car is impossible,

on account of the large amount of dust produced when travelling at a high speed. On the other hand, the designs showed that a great gain in weight is possible if air is passed through the cores of the transformers, and the insignificant amount of cooling possible from the surface of the casing is not alone depended upon. Two air shafts led from the roof (Fig. 4) to the transformers in such a manner that the front shaft was used for the admission of fresh air, and that in the rear for its emission after it had become heated. Special care was taken to withdraw the moisture from the air in rainy weather and to ensure that it is dried and filtered before it enters the channels of the transformers, although the actual contact of the cooling air with live conductors is avoided.

Further economy resulted from the use of a liquid starting device of an entirely new construction, instead of the metal starting device with coils or plates of resistance material at first provided (Section 3).

The following summarised statement shows how the weights varied in the different investigations :—

	Weight of Plant.		
	System I. (Fig. 1.)	System II. (Fig. 2.)	System III. Fig 3.
	kg.	kg.	kg.
4 Motors	16,000	16,000	12,800
(a) 2 Transformers	13,000	13,000	6,500
(b) Starting resistance with casing ... ... (c) Controllers with driving mechanism	9,000	9,000	4,750
(d) Braking and lighting batteries	2,600	2,600	2,600
(e) Motor with compressor ...	800	800	800
(f) Oil pump	200	200	—
(g) Oil tank	600	600	—
Total weight of cable	4,000	1,000	1,000
Trolley-poles	1,400	1,400	1,400
Total	47,600	44,600	29,850

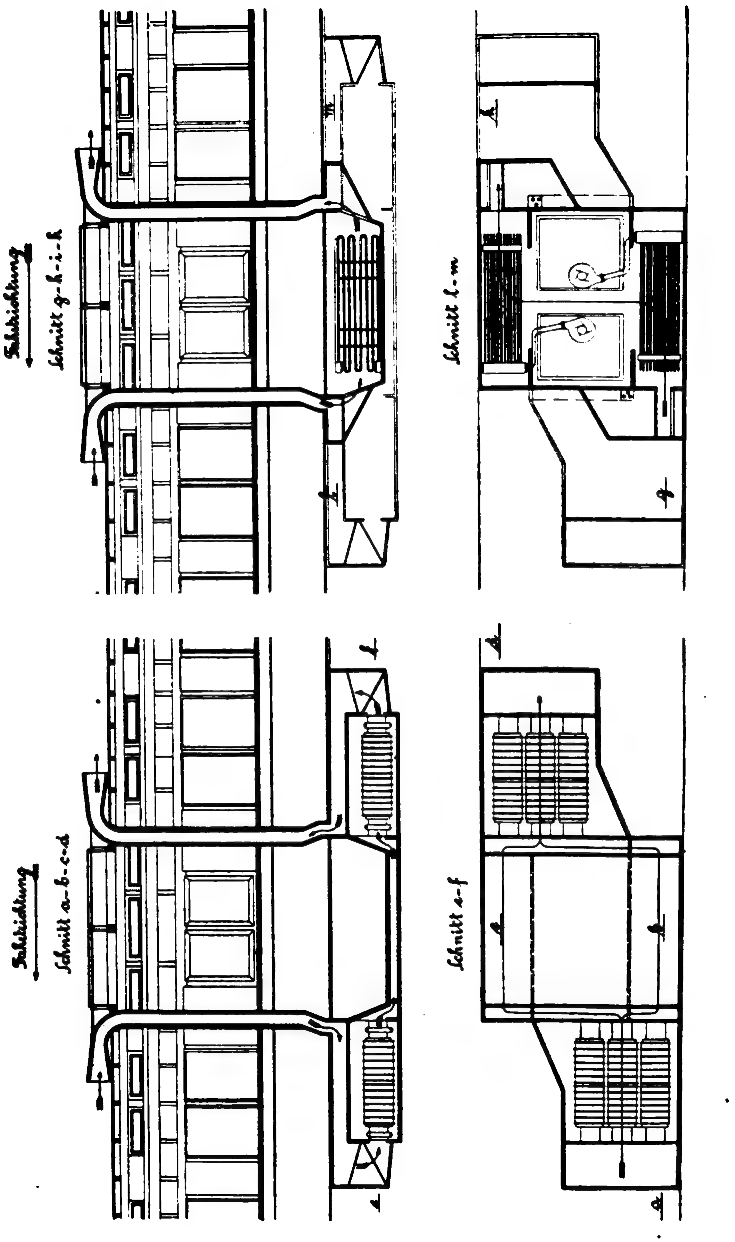

Fahrrichtung
Schnitt g-h-i-k
Schnitt l-m
Fahrrichtung
Schnitt a-b-c-d
Schnitt e-f

Fig. 5.

The final weight for the transformers was 6·5 kg. [14·3 lb.] per kw.; and, for the motors, 13 kg. [28·7 lb.] per H.P. of the normal output, and $4\frac{1}{3}$ kg. [9·5 lb.] per H.P. of the maximum output. The table shows the saving which resulted from the construction of the unenclosed motors (Fig. 5).

Like the new alternating-current dynamos and the stationary motors, the laminated iron magnets are not encased, but are directly exposed to the cooling influence of the air, the external surfaces of the motors being increased in area by the ribbed design adopted. Surface cooling was thus ensured in a convenient way: it was found to be fully sufficient even when the motors were running continuously. No provision was made for the admission of air into the motor, as, on account of the dust below the car, it was not possible to take the air from below, and there was no convenient way of supplying it from above.

2.—The Motors Spring-mounted upon the Axle or Rigidly Secured to the Axle.

Between the two extremes—(*a*) the body of the car mounted without springs directly on the axles, and (*b*) every part being practically mounted on springs, as in an automobile with pneumatic tyres—a large number of different combinations is possible. Electric locomotives of very small dimensions have been constructed, with the upper part in rigid (not spring-mounted) connection with the sets of wheels (Fig. 6). On the Central London (Underground) Railway, notwithstanding that a speed of 30 km. per hour is attained, the bogies of the locomotives are not mounted on springs; hence the severe vibration which has caused so many complaints. Other designers have adopted different constructions. Some have placed the motors directly on the axles (Fig. 7), whilst others have fixed them to the spring-mounted body of the car, or to the bogie (Fig. 8). The motors carried by the bogie have the same range of movement (due to the deflection of the spring) relatively to the wheel axles as the frame itself has, *i.e.*, up to a maximum of 60 mm. [2·3 in.] in one direction. Figs. 6, 7, and 8 show these three fundamentally different constructions for a set of wheels of 1,000 mm.

[3 ft. 3 in.] in diameter. The principal dimensions inscribed [in mm.] on the figures give an idea of the space available, and also show how much valuable space in Figs. 7 and 8 is absorbed by the bearings of the motor.

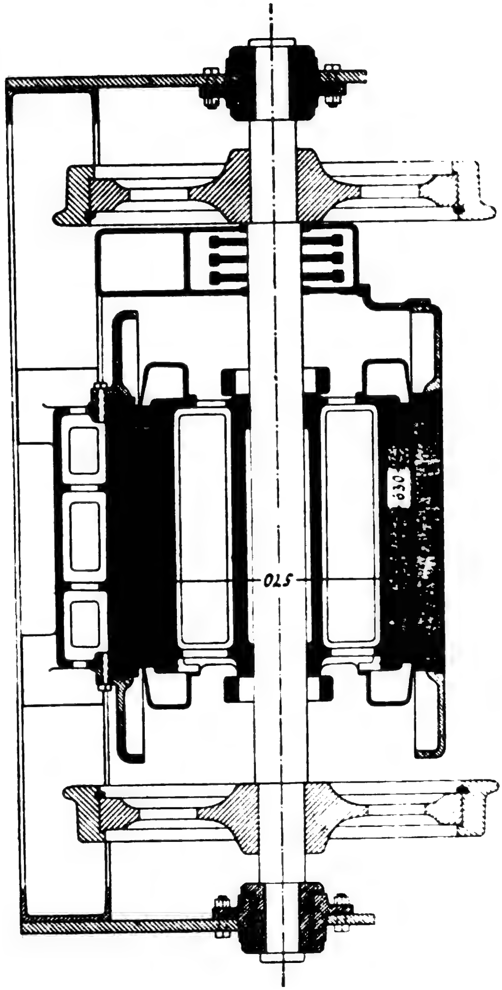


FIG. 6

The simplest construction is, of course, the rigid mounting of the axle on the bogie (Fig. 6). In this case the axle and motor have no motion relatively to the other parts of the construction; but, unfortunately, the axle-boxes

have here to ensure the central position of the revolving armature within the fixed stator.

In the construction shown in Fig. 7, the stator is kept

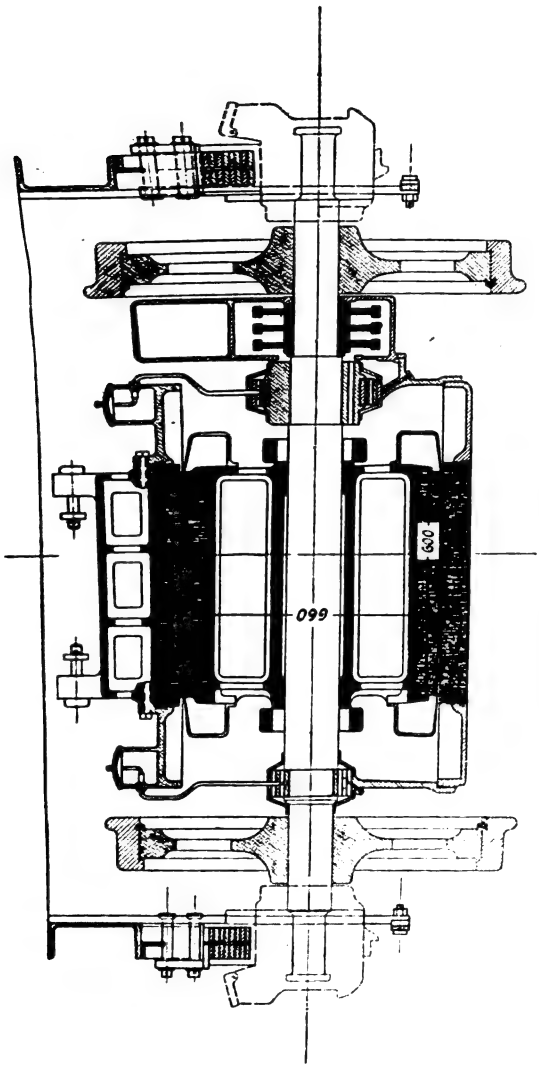


FIG. 7.

concentric with the rotor by being mounted on the same axle, which thus carries the weight of both, and the power is transmitted through the axle to the wheels. The stator

must be so connected to the frame that it is prevented from rotating.

In Fig. 8, the motor is shown rigidly connected to the bogie, which is spring-mounted on the axle. The indirect

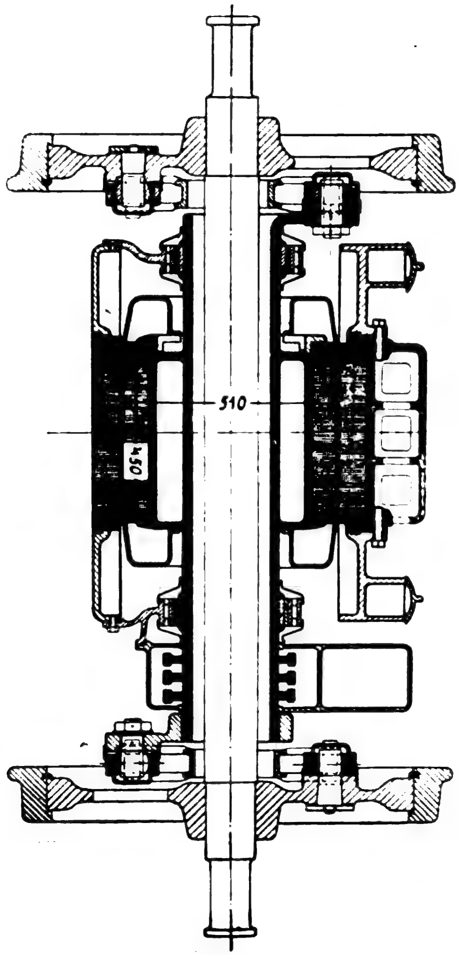


FIG. 8.

use of springs, in supporting the motor (by attaching the stator to the frame of the bogie) necessitates the use of a hollow shaft surrounding the axle at a suitable distance. This construction may be possible when the springs between the frame and the axles are not subject to such deflection as they are liable to in the high-speed car, where the play may

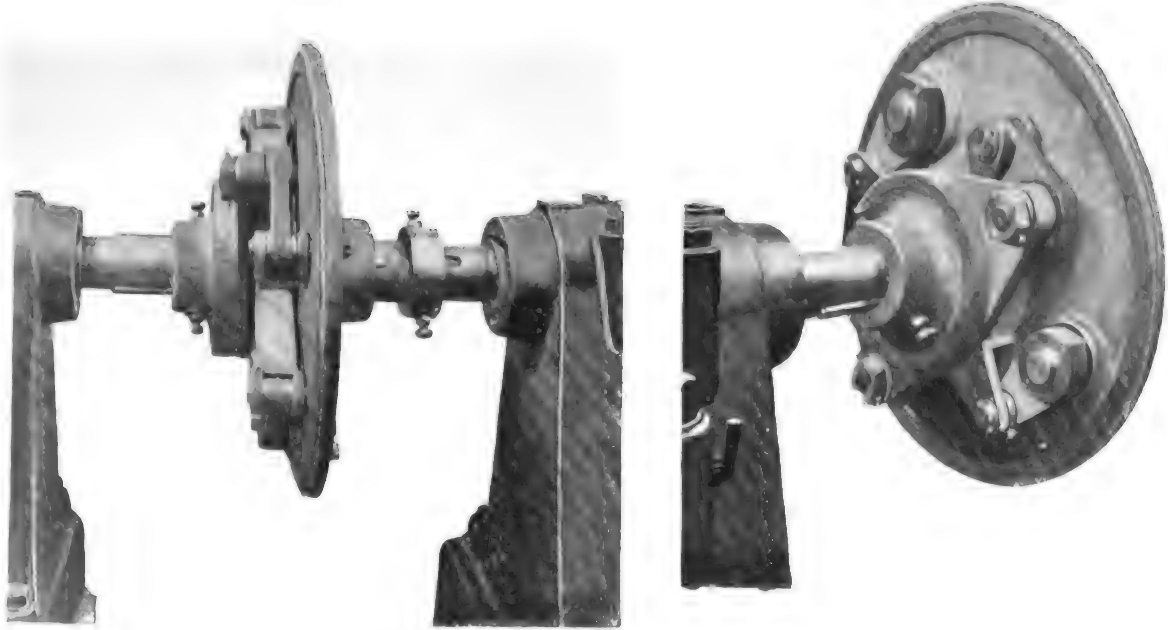


FIG. 9.

amount to 60 mm. or more. In this car there is a peripheral speed in the bearings of not less than 18 m. per second (3,540 ft. per min.) As no previous records were known of the use of white-metal bearings at these extraordinarily high speeds, a series of experiments was undertaken in this connection, quite independently of the other investigations. The material at first used for the hollow shaft was cast steel; but this was subsequently abandoned, and wrought nickel steel was substituted, because its surface is capable of taking a very high polish.

From the attempt to relieve the axle of the wheel from the very great additional weight of the motor, there resulted another difficult problem, namely, the designing of an elastic coupling to transmit the power from the hollow shaft to the axle and the wheels. The coupling first designed is shown in Fig. 9, photographed from an experimental arrangement tried in combination with an electro-motor and a dynamo used as a brake. This coupling in its essential features resembles a double crank system; but at the high speeds (about 1,000 revolutions per minute) to be employed, the combination of links and rods here indicated did not appear to be sufficiently safe. This design was followed by numerous others of various kinds, and the advisability of mounting the motor directly on the axle was again considered.

The great relative movement between the hollow shaft and axle was the chief obstacle to the construction of a safe coupling. Attempts were therefore made to find means to overcome it. The rigid attachment of the motor to the bogie was dispensed with, and the motor was supported by springs which were caused to bear against either the wheels or the axle. A movement of a few millimetres was deemed sufficient, especially in the former case, to protect the motor and its windings from shocks, such as might be produced by the hammering of the shaft on the axle, and to prevent undue strain to the axle and wheel hubs. The annexed sketches (Fig. 10) show the springs which carry the motor. The springs and rods which transmit the torque have been omitted in the sketches. The springs shown in sketch *a*, bearing against the rim of the wheel, were subjected to a considerable strain by the action of their own centrifugal force. Design *b* was not much better. Design *c*

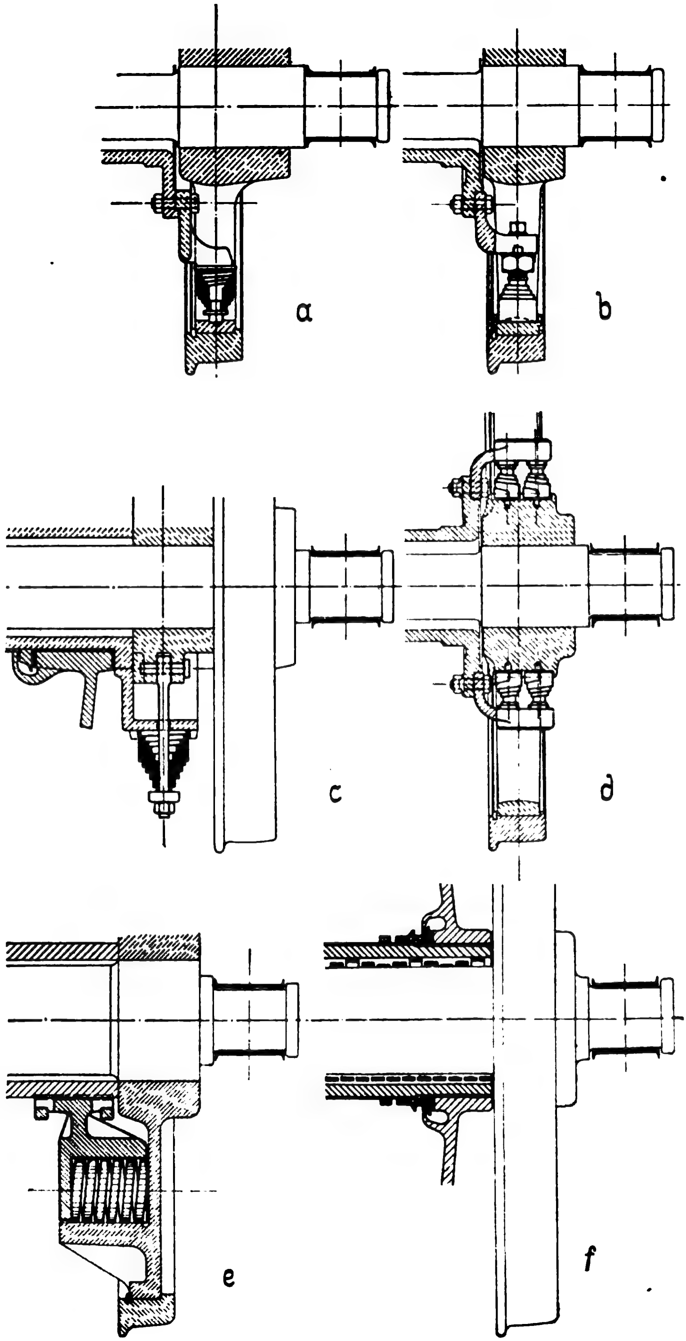


FIG. 10 (a; b; c; d; e; f).

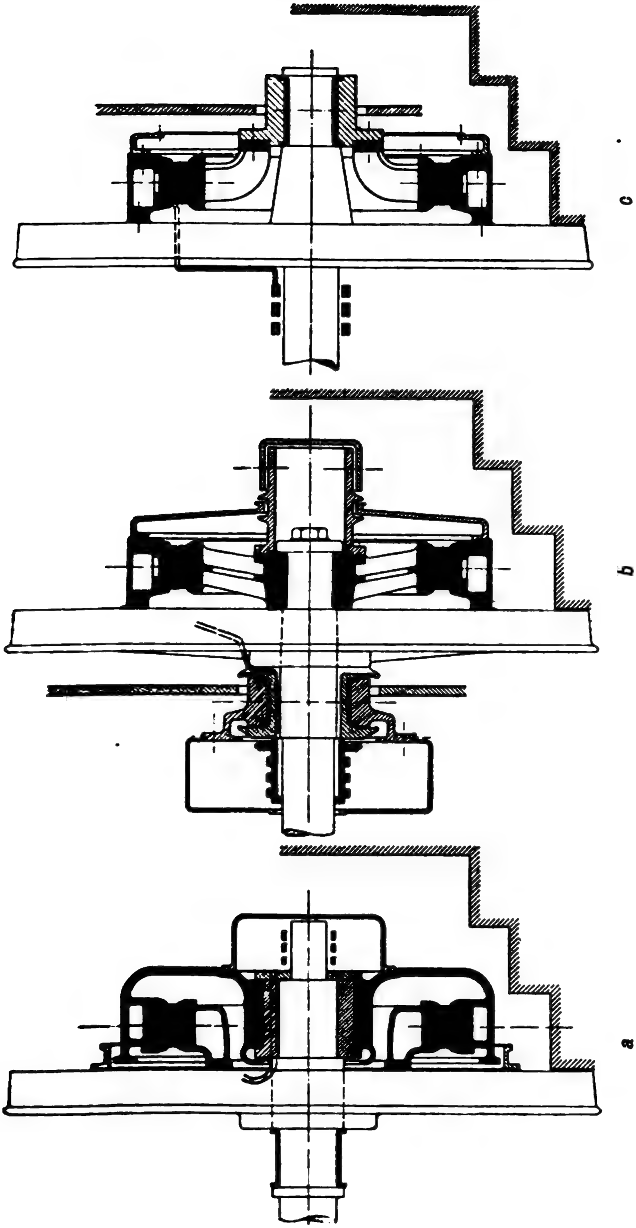


FIG. 11 (a, b, c).

is superior with regard to the action of centrifugal force, but the space occupied by the coupling was considerably greater than before. Sketch *d* shows the motor supported by springs bearing upon the hub of the wheel, as in design *c*, but in the latter case the support is effected by the cylindrical surfaces of a large number of spiral springs. Sketch *f* finally shows the possibility of transmitting the weight of the motor to the axle in a very simple manner by means of a spiral spring with an eccentric arrangement of its many coils. These couplings, however, did not give promise of being sufficiently safe in use.

In view of the difficulties just described, a further series of designs was worked out, having in view a reduction as

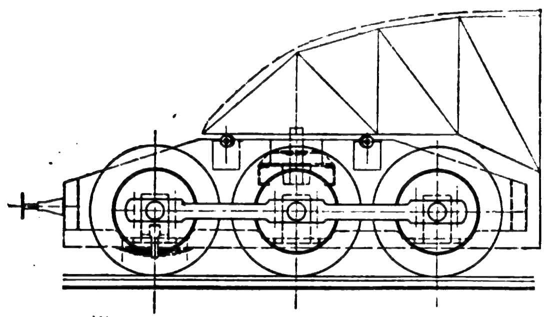


FIG. 12.

far as possible of the weights of the motors, with the object of attaining such a gross weight for the parts not mounted on springs as might appear to be admissible. Figs. 11, *a*, *b*, *c*, show such designs for the diameter of wheel at first adopted (about 1,800 mm.) the speed of the motors being correspondingly reduced. The motor was sufficiently accessible in *a* and *b*, but not so much so in *c*. In the latter case, however, the axle bearing was free. Larger wheels would have been more suitable for high speeds, since the number of revolutions of the motors, and consequently also the relative speed of the bearing surfaces, would have been lower; moreover, the vibrations or shocks caused by rail joints would have been reduced. But the part of the car located above the wheels could not then have been utilised, and a considerable portion of the length would thus have remained unused, as is clearly shown in Fig. 12. Similar investiga-

tions were therefore made with smaller wheels. Fig. 13 gives some idea of these investigations. The diameter of the wheel is here 1,250 mm., the speed of the motor being about 1,000 revolutions. The frame of the motor comes just within the standard structure gauge. These sketches

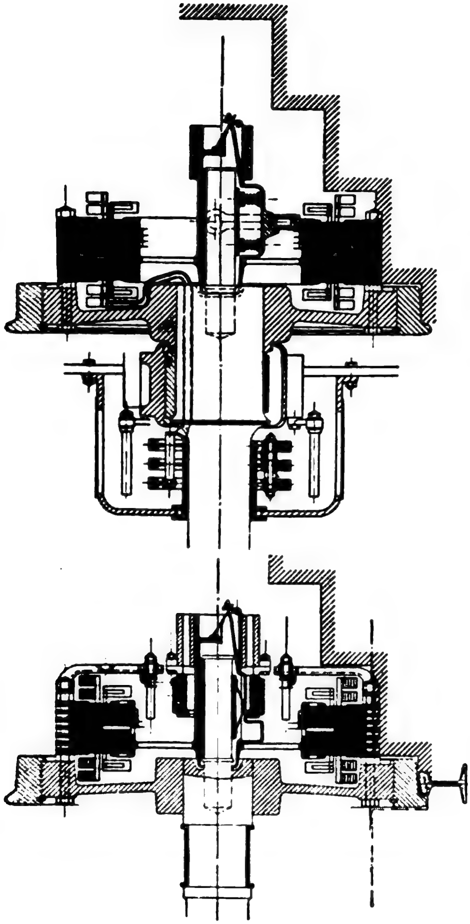


FIG. 13.

show the abandonment of the usual casing, leaving the ribbed magnet uncovered. Owing to the weight of such motors, the weight of each wheel-set was doubled. The number of the motors had to be raised from four to six for each bogie—*i.e.*, twelve motors for the car; and the resultant advantage appeared to be too small when the higher

price and the inconvenient arrangement of the cables that would have resulted were taken into account.

One of the chief difficulties in designing the coupling and bearings was, as above explained, the considerable deflection of the springs when the motor was attached to the car or bogie; it has been stated also that arrangements for supporting the motor from the axle by means of a number of small springs did not appear to afford sufficient security, although the motion of a few mm. should be sufficient. The motor was no longer connected with the frame of the bogie, but it was supported by strong springs bearing against the axle box. These springs had to deflect but a few mm., as stated before. Owing to the use of an adjustable curved block, "*a*" Fig. 14, this spring bends very readily for the first one or two mm., then it grows stiffer up to a maximum of 8–10 mm. Fig. 14 shows the construction of this arrangement. The motor is firmly screwed to a frame of sheet-iron with channel-iron bars. This frame is supported on both sides of the car on plate springs, resembling the usual car springs, the buckle being mounted by means of the buckle of the axle spring at the axle box. The motor is prevented from moving laterally by suitable abutments, which bear against the slides *b*. Means were also provided to prevent rotation of the stator in either direction. Certain slight alterations which were made during the manufacture will be referred to later. With this simplified construction, it was possible to make the coupling shown in Fig. 15*a*. A ring consisting of 3 parts was mounted at each end of the hollow shaft; in each of these parts double arms were fitted in the form of bundles of springs. The ends of these plate springs bear against guide pieces fastened to the wheel. This sliding and elastic movement allow of a steady and constant motion of the hollow shaft relatively to the axle. There was some uncertainty at first as to the working of the coupling, and Fig. 15*b* shows another design that was made. The coupling, Fig. 15*a*, contains sliding parts, and is therefore subject to a frictional resistance. In the form shown in Fig. 15*b* this frictional resistance is diminished to less than one per cent. of its former value, or, in other words, it is practically obviated. Calculation showed that, with the construction *a*, the coupling allowed a deflection of the motor-suspension

FIG. 15a.

when going at full speed, if the slope of the track changed by as small an amount as 5 mm. in every 5 m., or of 0·5 mm. in 1·5 m. of track. This degree of sensitiveness should be sufficient; if not, the parts shown in Fig. 15*b* could be introduced without difficulty.

The reduction in the deflection of the spring allows

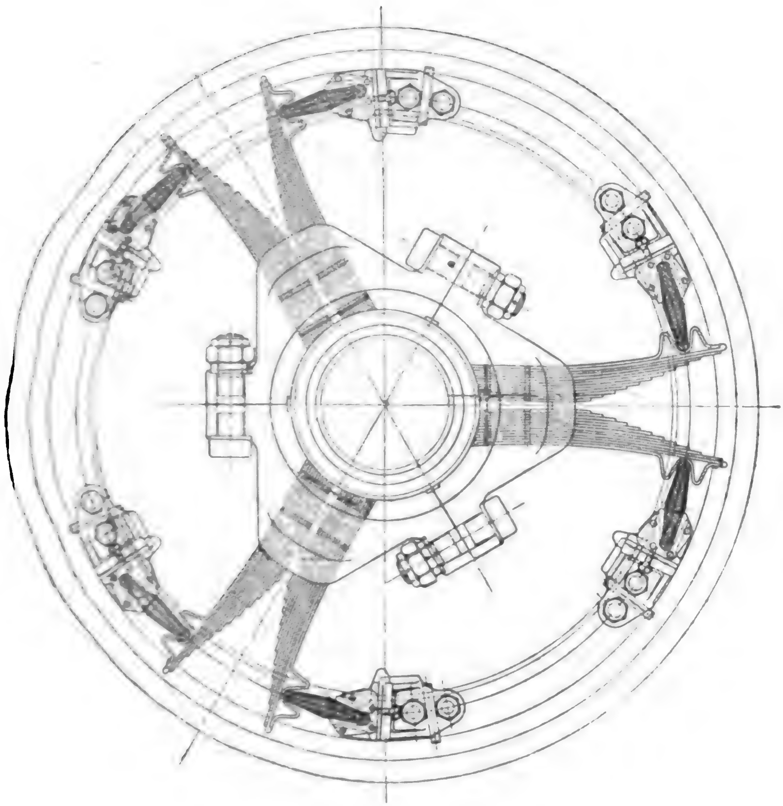


FIG. 15*b*.

the diameter of the hollow shaft to be diminished, and so the construction of the bearings is simplified, and their lubrication is facilitated.

Fig. 16 is taken from a photograph of the experimental arrangement, built in the Mechanical Experiment Department of the A.E.G., for the purpose of examining the working of bearings at very high peripheral speeds. In

imitation of the stress to which the motor bearings would be submitted, an upward pull was imparted to them, and the pressure was ascertained by means of an interposed spring balance. A block of nickel steel, of the material, diameter, and shape adopted for the bearings (260 mm. diameter), was used for the shaft. This block was mounted on an axle 100 mm. in diameter, secured in long bearings with white-metal brasses. The whole arrangement was driven by an electromotor, the power supplied to which could be ascertained at any moment. Tests were made almost exclusively with brasses of white-metal and axles of nickel steel, but a few experiments were also made with cast steel, and with brasses of magnolia metal. As regards the system of lubrication, considerable changes were made in the course of the experiments. At first, oil under pressure was provided, in order to feed each of the bearings separately from one central point. This necessitated a supply of oil under pressure through the whole car, with pipe connections that were somewhat cumbersome, in order to allow for the turning of the bogies and for the relative movements between the axles and the body of car. Lubrication with oil under pressure was soon dispensed with, and a rinsing system of lubrication (*i.e.*, an adequate supply of oil, without pressure) was adopted. For railway purposes, of course, the usual ring lubrication could not be used, whilst some of the other recognised methods either were not reliable enough or caused a frothing of the oil. A smooth disc of large diameter mounted concentrically on the axle, raised the large quantity of oil required admirably, without producing any froth. Experiments were made at speeds varying from 2 m. (the normal speed) to 25 m. per second, and at pressures ranging from 2 to 5 kg. per sq. cm., to ascertain the relation between speed, bearing-pressure and temperature. Full particulars of these experiments will be published at some future date; meanwhile the three-dimension diagrams, given in Fig. 17, indicate sufficiently well some of the results obtained.

3.—Starting Devices.

In the investigations relating to the main division of the car and to the arrangement of the electrical parts to ensure

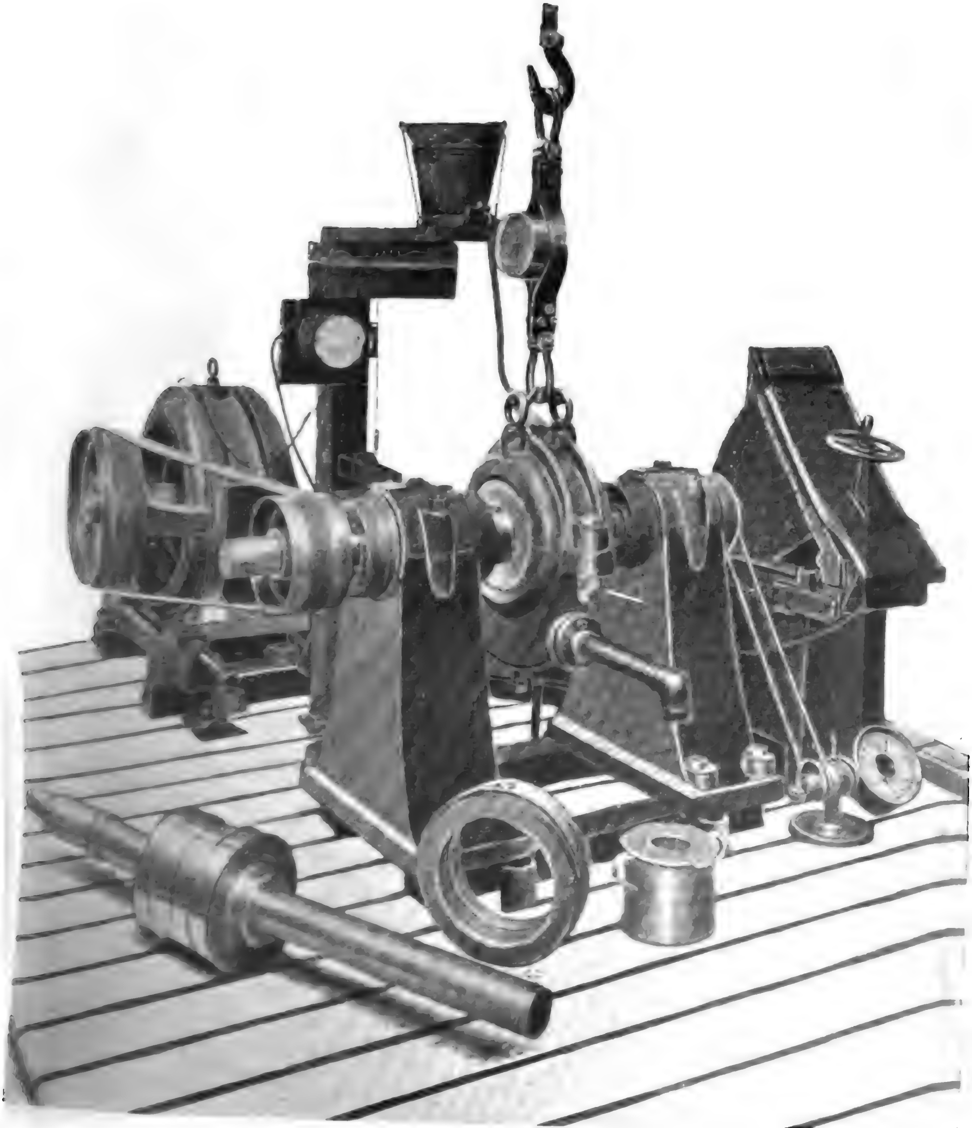
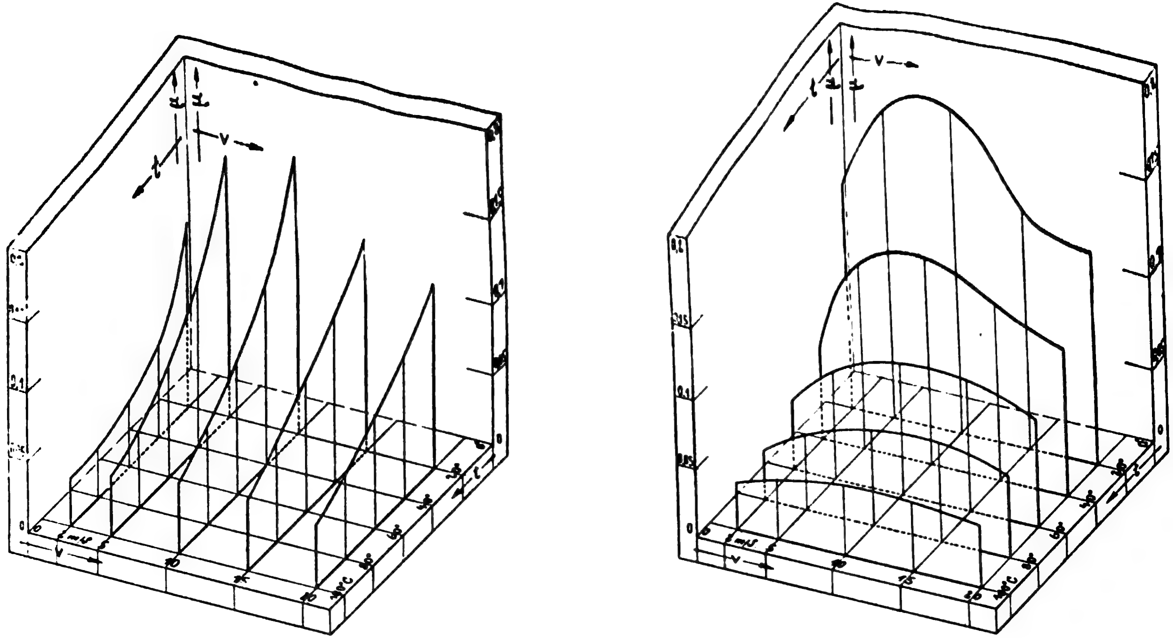


FIG. 16.



NOTE: In these diagrams:—

t, is the temperature of the bearing at the time of observation. It is capable of variation in different experiments by altering the rate of flow of oil to the bearings.

v, is the peripheral speed of the axle in the bearings, expressed in metres per second.

μ, is the coefficient of friction.

The axle was of nickel-steel, the bushes of white-metal.

FIG. 17.

the attainment of the minimum weight, it was mentioned that the starting apparatus was mounted in the middle of the car so as to allow of the cables being as short as possible. The laying of the high-tension cables, and the arrangement of the fuses and switches in the primary circuit, will be described in the account of the car in Part II. In the present section reference is made only to the resistance apparatus adapted for regulating the speed, and for starting and braking. From the very first, the primary circuit of the motors was provided with a switch to reverse the direction of running, and to cut out and brake the motors either by a counter current, or by connecting the stator windings with a storage battery.

It was at first intended that liquid resistances should be used in starting and regulating the current, the construction ordinarily used for starting either small or large motors being employed. Thus, wrought iron sheets were to be inserted in the armature circuit of the motors in such a manner that connection would be established by the liquid, and the rotor circuit would thus be closed; it would then be opened by withdrawing the sheets from the liquid. The resistance becomes smaller or larger according to the area of the immersed electrode surfaces, and consequently the slip of the rotor relatively to the theoretical number of revolutions also becomes correspondingly smaller or greater. In other words, at the commencement, the speed of the motor is small and increases as the surface of the iron plates immersed in the liquid becomes larger. Fig. 18 shows such a starting device, the disadvantages of which are sufficiently well-known. The liquid closes the circuit, but introduces a resistance, and thus becomes heated. The heating of the water takes place rapidly, because the heat imparted to it cannot be conducted away, but remains in the liquid, which soon begins to froth and boil. Hence, as the name "starting device" indicates, it can only be used for starting, and not as a speed regulator.

For constructive reasons, the electrodes cannot be placed sufficiently close together to produce a short circuit even when totally submerged, and it is therefore necessary to use a metallic short-circuiting device. A further difficulty in the case of large motors is that involved in the movement of heavy electrodes.

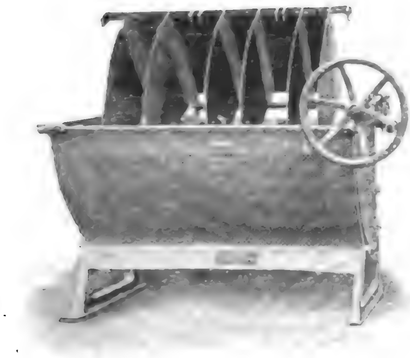


FIG. 18.

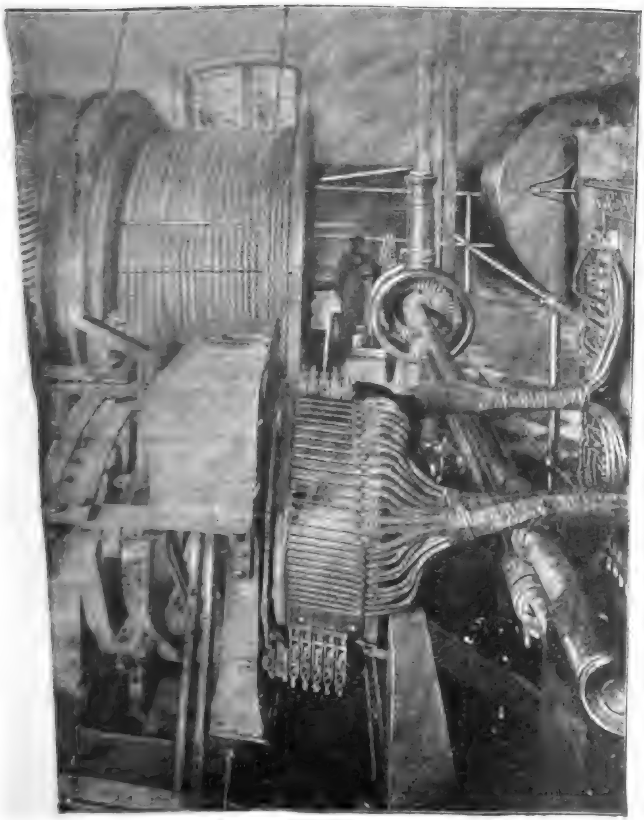


FIG. 19.

The A. E. G. have constructed such liquid starting devices for large motors up to several hundreds of horse-power. Other methods of construction were also tried, in which the electrode plates were stationary, and the liquid passed from a separate reservoir into the electrode receptacle. Such an arrangement, using compressed air for raising the liquid, was also proposed for use on the express railway car; but the above-mentioned drawbacks necessitated the employment, at first, of metallic starting devices.

The special requirements of the case—namely, the provision of a very small floor-space and of means for permanent regulation, the arrangement of contacts and connections clearly in view, and the certainty of easy and safe manipulation from the driver's platform—created a difficult task for the designer, in view of the unusual output of 3,000 H.P. to be employed.

The starting and regulating apparatus had to be proportioned for this maximum output because, during the time of switching, motors have to develop their full power. The regulating apparatus must also be calculated for the full load. Separate switching cylinders were used for each motor and for each rotor circuit; and in order to minimise the number of the cylinders corresponding to the four motors, two-phase wound rotors were adopted. The result was that eight cylinders were used instead of twelve. When starting the motors a large number of resistance-coils must be switched into the rotor circuit, so that the motor gradually receives its full rotor-voltage and the full current.

The larger the number of steps, the more inconvenient are the connections of the cables and the many resistances. Fig. 19 shows what an enormous number of cable connections must be used for a starting apparatus built for a hauling engine of scarcely 100 H.P. With the present output of 3,000 H.P., it appeared almost impossible to ensure that the necessary connecting cables should be accessible. The minimum number of the steps to be used is determined by the volume of the rotor current, and by its voltage. The difference of potential from one step to the next, *i.e.*, from one contact of the switching cylinder to the other, must be kept within certain limits, in order to avoid sparking at the contacts, even though provision be made for the extinction of an arc.

It had been assumed for the purpose of the experiments that the speed of the dynamo supplying the current could be considerably reduced, so that there would be a proportionate reduction in the speed of the car; but this is insufficient, because, although it is possible to run at half-speed, a speed even of 100 km. per hour is too fast for the commencement of the trial runs. It was thus necessary to rely on permanent regulation, *i.e.*, on the permanent introduction of resistances. Of course, only the resistance coils so switched in are subject to heating, and the resistances previously cut-out are not used.

While making these investigations, the task of constructing starting and regulating appliances for large hauling machinery presented itself to the A. E. G. It seemed impossible to apply the existing types of small hauling machinery, whether of the A. E. G. or of any other maker, with a maximum output of about 100 H.P., to plant using 3,000 H.P. All these hauling engines, with the exception of a plant of about 80 H.P., which has been working for the past 6 years in the pit Hollertzug, near Herdorf, with an economical method of regulation (*i.e.*, without any current being converted into heat), are constructed throughout with resistance regulating devices, whether they are driven by direct current or by three-phase current.

The problem was finally solved by a liquid-starting device on an entirely new principle. Fig. 20 shows an experimental arrangement of this device. A three-phase motor of 200–400 H.P. is coupled direct to a very heavy fly-wheel. In order to bring this up to full speed in 15 seconds, a torque corresponding to an output of 400 H.P. must be attained. With the same output, another heavier fly-wheel was made to run at full-speed in 1½ to 2 minutes. The former meets the requirements of a hauling engine, the latter those of the high-speed car. The high-tension switchboard at the back is arranged to allow of reversing the fields. A combination of these connections with the starting device proper was omitted in the experimental arrangement.

The photograph shows in the foreground a small centrifugal pump driven by an electromotor, which raises the liquid from a reservoir in the basement, and continually delivers it into the tank in which the electrodes

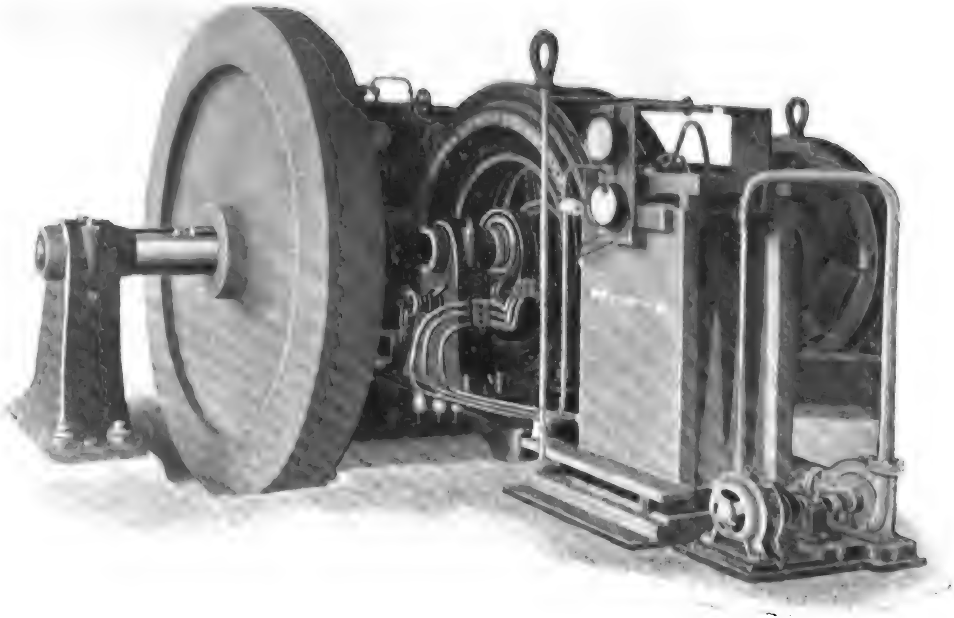


FIG. 20.

(*i.e.*, the terminal or end plates of the opened rotor circuits) are located. The pump operates continuously; hence a constant renewal and mixing of the liquid takes place, and the electrodes are thus suspended not in stationary but in moving water. By shifting the somewhat primitively arranged vertical rod to the right, a valve in the bottom of the tank is closed, by which the water would otherwise have been continuously discharged. The liquid now begins to rise in the tank, and the rotor circuits are closed, so that the motor starts, but of course with a considerable resistance in circuit. As the liquid rises in the electrode tank, the interposed resistance decreases, and the motor runs more quickly. Consequently, for a certain load, each level of the liquid represents a certain speed of the motor. By means of a regulated overflow in the electrode vessel, the level of the liquid can easily be adjusted, and consequently the motor can be run at any required speed, as for instance in the case of a winding engine when an inspection of the mine-shaft is taking place, or when men are being conveyed in the cage, or, in the case under consideration, when it is required to make the high-speed car run at 50 or 60 kilometres per hour.

The electrode plates are very wide apart at the lower end and are made with prong-like extensions of different lengths. The arrangement is such that the longest prong of the first plate is situated diagonally opposite the longest prong of the other electrode; thus, at first, not only are the dipping surfaces small, but the distance between them—that is to say, the path of the current through the liquid—is very considerable. The immersed surface of the plates can therefore, on account of the great distance, be considerably larger than might be the case for the passage of the same current through a small distance. In consequence of this, any overheating of the points or tips such as occurs in the old form has become impossible. On the other hand, the electrode plates are placed very close to each other at the top, and a larger number of plates than formerly are used, in order to keep the conducting surface for the current very large, thereby reducing to a minimum the resistance of the liquid to the passage of the current, and obviating the use of metallic short-circuit contacts.

The essential difference between the new starting device and those previously used consists in the maintenance of the liquid in constant motion—a fact which alone suffices to ensure its use. The heated liquid does not remain at the point where heat is being generated, but is constantly circulated and mixed afresh. It is easy to calculate what amount of heat is communicated to the liquid by the resistance at any given load or for a given decrease in the normal speed; and the use of water in motion renders it easy to conduct away this heat. The cooling surface necessary to effect this may be readily calculated; and in the present construction of the high-speed car (Fig. 4) systems of serpentine copper tubes of small diameter are provided, through which the heated water has to pass after leaving the electrode vessel and before it is used afresh. Consequently the new liquid starting device enables any suitable large resistance to be brought permanently into the circuit, and the motor can be run continuously at any slow speed that may be required.

The starting period of the motor, viz., the period from rest up to the time at which the resistance is entirely cut out, is determined by the speed at which the liquid flows into the vessel. By inserting an adjustable valve in the pipe leading from the centrifugal pump, the speed at which the liquid is delivered (and consequently the starting period) can be regulated at will. By this construction it is therefore rendered possible to prevent the driver from reducing the time required for starting; hence the acceleration, and therefore the torque, can never prove greater than the overloading capacity of the motor permits. On the other hand, the driver can, by a corresponding slow or incomplete closing of the foot valve, decrease the speed for starting and braking to any desired extent. In a similar manner the driver can run the car at any desired slow speed by keeping the foot valve partly opened. Consequently the speed is under perfect control. This new arrangement when contrasted with metallic starting devices also shows the great advantage of a continuous, as compared with an intermittent, switching in or out of the resistance; it ensures that the starting and braking are effected smoothly and not by jerks. Any one who has experienced the jerking motion of tramway cars can realise how greatly the above arrangement will be appreciated by the passengers.

Owing to the great simplicity of the apparatus it can be readily operated from a distance, as the power required is excessively small. Consequently, the provision of compressed air or electricity in the car, as a means of operating the regulating mechanism, is rendered unnecessary; all that has to be done is to provide a connecting shaft operated by a hand wheel from each driver's platform.

When using the new system of liquid starting device, the metallic arrangement is no longer needed, and the several hundred contacts and cables are dispensed with. In regard to maintenance, no fear need be entertained, since of course the maintenance of plates not liable to become rusty, immersed in a soda solution, cannot be compared with that of many and large controller cylinders, contacts, contact brushes, cable connections and pieces of resistance material.

4.—Brakes.

The system of electrical braking with the aid of the motors was also tested by means of the same experimental arrangement that had been constructed for testing the starting apparatus.

The car is equipped with a Westinghouse compressed-air brake, divided into two parts for each of the two bogies. The compressed air cylinders are operated from the front driver's platform. The brake pressure is assumed to be very high, 170 per cent., because the coefficient of friction between the brake block and wheel at the high speed employed (above 50 m. per second) is materially different to that at the usual lower speeds. In consequence of investigations that have been made, an appliance has now been devised for decreasing the brake pressure at a slow speed. Notwithstanding the fact that to a certain extent the brake arrangement of one bogie forms the reserve for the other, it was not considered admissible to dispense with a second brake. This additional braking action was imparted by the motors themselves and not by special rail brakes or similar less approved apparatus.

The braking may be effected by means of the motors in two different ways. The first method is by resistance braking, in which the stator of the motor is excited by

continuous current and the rotor gradually short-circuited, so that the motor works as a generator on the resistance. In the other method the direction of the current into the rotating field is changed, causing the field and the rotor to tend to rotate in the opposite direction.

Both methods of braking are used in the high-speed car. After the rotor circuit is opened by opening the outlet valve of the liquid controller, the field is, by means of a change-over switch, first opened, and then switched on to a storage battery placed within the car ; or, two of the phases bringing current to the motor are interchanged, causing the series arrangement of the phases to be changed from 1, 2, 3, to 1, 3, 2. After the switching has been effected in either way, the rotor circuit is gradually closed again, *i.e.*, the inflowing liquid makes contact through a very great resistance, and the level of the liquid is then raised or lowered according to the amount of braking action that may be desired.

Braking by means of reversed stator current alone did not appear to be sufficient, because the current was apt to fail for some reason or other, as, for instance, by the melting of a safety-fuse at the very moment when the brake was applied. The use of a reversed current has a further disadvantage. In consequence of the electrical construction of the motor and the potential of about 430 volts selected for the stator, the rotor has an electric pressure of about 325 volts on open circuit. After the reversal of the field, the tension in the rotor increases at full speed to almost double this amount, viz., to about 650 volts. Although the liquid starting device is intended for this voltage and the motor rotor is also fully capable of sustaining it—it was tested at 4,000 volts—yet it appeared unwise to allow the safety of the braking action to be dependent on an unusually high voltage just at the time when the brake is brought into action, and when there is a possibility of danger. These were the reasons which led to the provision of a resistance-braking system, and for this purpose there were provided two entirely separate storage batteries, corresponding to the two separate air receptacles for the Westinghouse brake. It is here assumed that motor braking must be made use of at high speeds, and that the air brake is only applied at the end of the run. For

shunting service, a hand brake is also provided to act on the front bogie.

5.—Trolley-Bows.

The current is led to the three wires placed vertically one above another, from which it is taken into the car through bow-shaped collectors. By this system of taking the current, in which a deflection of the trolley wire between the connecting points does not affect the bow, the jumping of the latter is more readily avoided than if it made contact from below. Notwithstanding this fact, the question of the trolley-bows had to be very carefully studied, and although the requirements for a speed of 50–60 m. per second could *only* be very incompletely complied with, an experimental arrangement was nevertheless made.

Three arms are arranged on the roof at each end of the car, one for each of the three phases. The distance between the arms is determined by the space required by the bows when being turned around their vertical axis. These distances are, however, made as small as possible, and the arms are located close to the pivots of the bogies, so that there may be no material change of the distance to the wires in passing around curves. Two sets of bows were considered necessary, so that, in the event of one bow failing to act, the current would be taken from the other, and no sparking would occur.

Further steps were then taken in the direction of increasing the number of contact surfaces, and of reducing as far as possible the mass of the metal which has to slide along the wires. A number of aluminium bows were connected to the trolley pole by plate springs of different lengths. The object of this elastic arrangement was to ensure a good permanent bearing on the wire; but in the event of one bow failing to make contact, the others must be sufficient to carry the current. In the event of greater deviations of the conducting wire taking place, the main spring arrangement of the whole arm will begin to act. Further particulars are contained in that part of the description which treats of the manner of taking and supplying the current.

PART II.—DESCRIPTION OF THE CAR AND ITS ELECTRICAL EQUIPMENT.

6.—The Body of the Car.

The car specially constructed to suit the electrical equipment was built by the firm van der Zypen & Charlier, of Cologne-Deutz, to accommodate 50 passengers. The over-all dimensions of the body of the car (including the apparatus compartment and driver's cabs), are 21 m. [69 ft.] and the distance between the buffer plates 23·10 m. [72½ ft.]. The full width of the car is 2,600 mm. [8 ft. 6 in.]. The body of the car is within the standard structure gauge throughout its length, but (especially in the middle part with its wide air-ports) there is not much margin to spare in this respect. The windows of the car are closed, ventilation taking place through the side windows of the lofty sky-light. On either side, at each end of the car, doors are provided to allow of the entrance and exit of the passengers.

The driving platform is separated from the passengers' compartment by a wide partition extending from the bottom to the top of the car and serving as a back support for the driver. At the sides of this partition are grated doors which, during stoppages at stations, are arranged in such a manner that the compartment remains shut off from the passengers, without interfering with the free access of the latter to the interior of the car. During the run these doors are so adjusted that they prevent the passengers both from reaching the exit and from disturbing the driver. The car is divided into two compartments by that containing the apparatus. The passengers can, however, freely pass from one compartment to the other, even when the car is in motion, as the apparatus compartment is protected in the same way as the driver's platform. Any portion that is liable to be touched from the gangway either does not carry current or is suitably insulated.

As will be seen in the chapter devoted to the arrangement of the cables, there are no parts through which current flows either in the passenger-compartments or in the driver's platforms. The trolley-bows on the roof of the car are fitted with two insulators connected in series, each of which is tested for a potential of 20,000

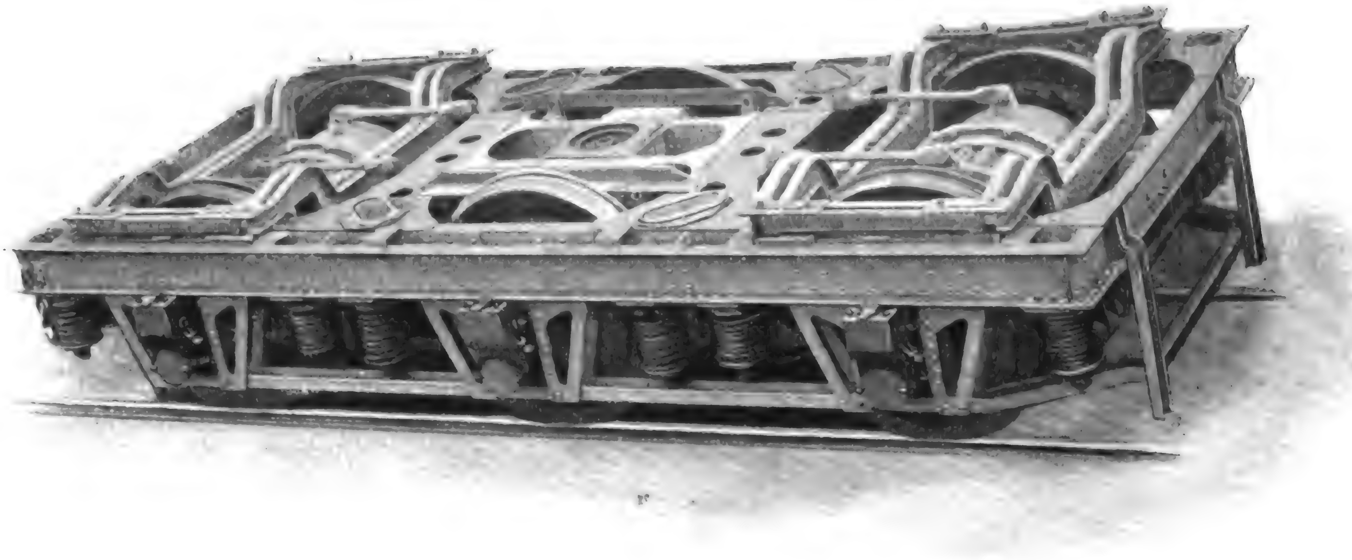


FIG. 21.

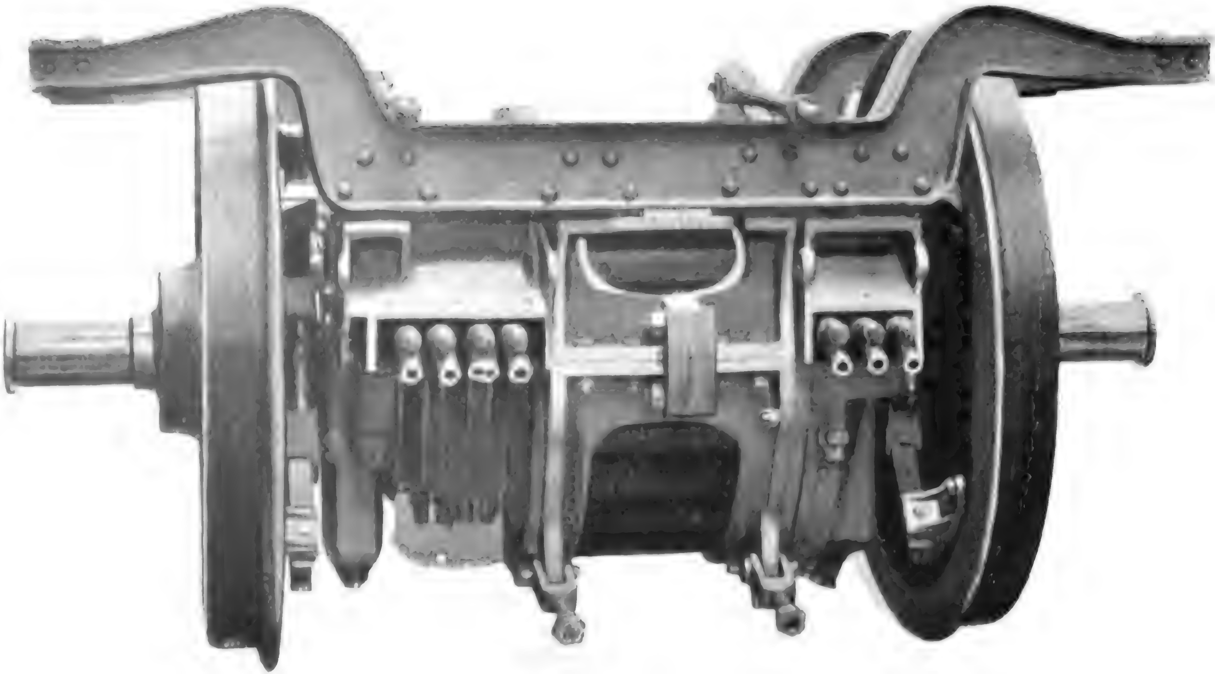


FIG. 22.

volts. The high tension current passes from the bows to the transformers through high-voltage cables which, in spite of their having been tested for 20,000 volts, are laid in high-tension insulators. Between the so-called apparatus-compartment and the passenger-compartments, and also between the latter and the transformers which are suspended below them, there are air shafts which form a double-walled enclosure. The storage batteries alongside the transformers are likewise separated off by double sheet metal walls.

The body of the car in its present form is not of the shape that would be expected for a vehicle running at a high speed. The car is slightly curved at the front, and not formed with a slope like the prow of a ship. The statements concerning the experiments which were made in this respect are contradictory, although they prove that a sloping arrangement is of no advantage. One object of the experiments about to be made is to clear up this point, and to ascertain the variation in the consumption of power at different speeds and when the car is exposed to head- or side-winds. A suitable screen can be constructed at any time.

7.—The Bogies.

The two bogies, which carry the body of the car, are 13·3 m. [43 ft. 7 in.] apart. The diameter of the wheels was assumed to be 1,250 mm. [49·2 in.], which allowed for a sufficient turning movement of the bogies below the car, without necessitating any alteration in the floor-level at any part of the car.

Each of the bogies has 3 axles, the two outer axles carrying the motors, while the middle axle allows the necessary space for the pivot and for the air-cylinders of the Westinghouse brake. The distance between the wheels measures 2 × 1,900 mm. [12 ft. 6 in.]. Fig. 21 shows one of the bogies and the arrangements of the motors within it. The load for each axle is less than the maximum allowable, and amounted to a little over 14 tons.

No springs bearing against the body of the car are provided. The bogies themselves are supported on the axles by two sets of springs; and each axle box carries a strong plate spring, to the heads of which are attached supporting springs carrying the frame.

On these axle-boxes rests the buckle of the axle spring; plate springs are provided to carry the motor. The connection between this spring and the motor frame is established by a curved block, against which the spring

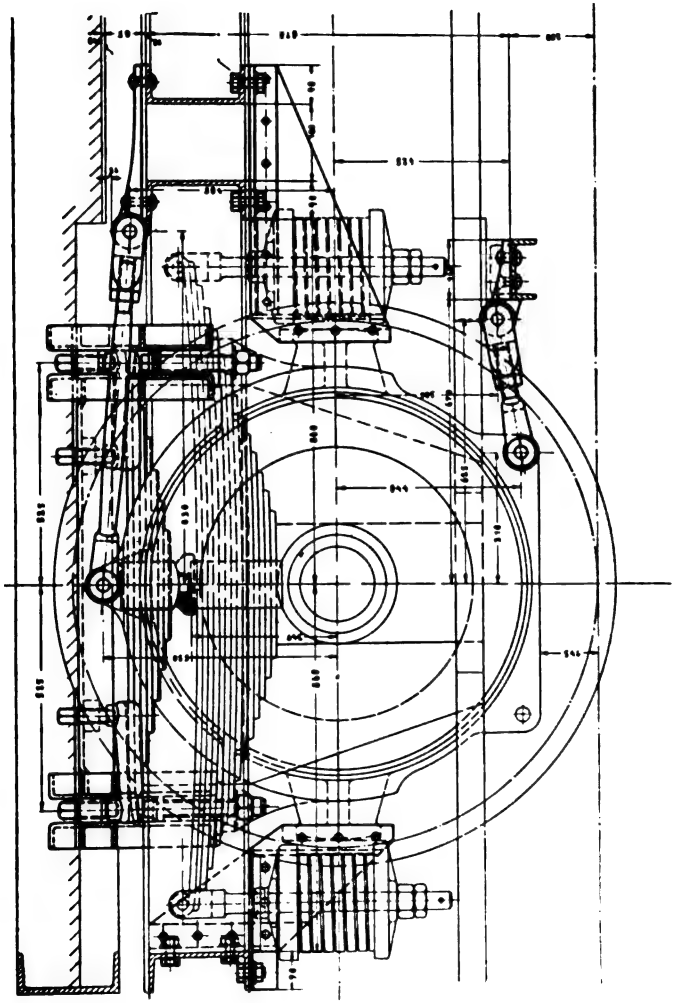


FIG. 23.

bears. By means of these shoes the spring action or its degree of elasticity can be varied. For the first few millimetres it acts as a very mild spring, then it gradually becomes more rigid, and at a deflection of 8–10 mm. it is quite stiff. In the almost impossible event of these strong

FIG. 24.

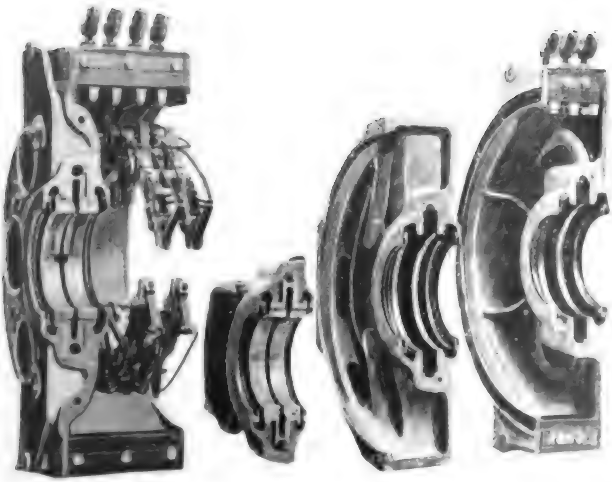


FIG. 26.

springs breaking, the motor would be supported by the wheel axle with the interposition of a suitable metal packing, placed close to the side of the wheel-hub. The conditions to be observed in the selection of the material for this packing were, that the material should be sufficiently soft to protect the axle and hollow shaft, yet of sufficient resistance to allow of the car being brought to a standstill before serious damage could be done. The motors are firmly screwed to a frame formed of rolled plates riveted together, and are protected against lateral movement by guide blocks, which bear against a corresponding guide on the frame of the bogie. The stator is prevented from turning round by bars which only allow of a vertical movement of the motor, Figs. 22 and 23.

The transmission of the power from the motor to the wheels is effected, as already indicated in Part I., by an elastic coupling which is entirely independent of the bearing.

8.—The Motors.

Each of the 4 motors is adapted for a normal output of 250 H.P., and for a maximum output of 750 H.P. The speed of the motor is about 960 revolutions per minute, which corresponds to a car-speed of 225 k.m. [140 miles] per hour. The tension of 12,000 volts, at which the current is supplied from the overhead wire, is reduced in the transformers to 435 volts. This voltage was adopted so as to permit of the motors being constructed with the bifurcated winding shown in Fig. 5. Although the motor, as above-stated, is not subjected to severe mechanical shocks, it was nevertheless deemed advisable, to ensure permanent safety in working, to have only one single bar in the separate grooves instead of a number of wires insulated from each other by cotton covering. The insulation of the bars from the iron is effected by closed micanite tubing. The rotor-winding (at the tension of the regulating apparatus), like the stator-winding (transformer low-tension) is also bifurcated (Fig. 24). For sake of convenience in the starting apparatus and the arrangements of the cable, the rotor was wound for only 2 phases and not, as is usual, for 3 phases.

The stator (Fig. 25) by means of two bearings, carries the hollow shaft on which the rotor is built up. One of

these bearings, Fig. 26, carries on its upper half the brush gear for making contact with the slip rings, and the connections for the cables of the rotor circuit which lead to the regulating apparatus. The cables of the stator circuit are passed through the other bearing. The bottom halves of the bearings can be easily removed to allow of the removal of the brasses, and to give free access to the brush gear.

In Part I. particulars were given as to the requirements to be fulfilled in arranging the journals for the hollow shaft. Fig. 25 indicates this construction and shows the method of oiling the bearings. The level of the oil is so regulated that when the motor is in full work, the disc which has to lift the oil dips into it to a depth of 30–40 mm. The material used for the bearings is the white metal alloy usually employed on the Prussian state railways; nickel steel was adopted for the hollow shaft, both on account of its polishing capacity and of its great strength.

The radial distance between this hollow shaft and the axle is 30 mm. [1·18 in.]. Copper rings are forced into the hollow shaft at both ends close to the hub of the wheels. The hollow shaft is prevented from lateral displacement by one of the motor bearings, a guide is used against only one of the bearings, so that expansion due to heating of the material may not produce binding between the axle and the bearing. The spring couplings are fixed to the hollow shaft at both ends.

The object of this coupling (Fig. 27) was to transmit the power developed by the motor—750 H.P. maximum at 960 revolutions—from the hollow shaft to the wheels, at the same time allowing the latter a displacement of 10 mm. relatively to the coupling arms. Hence the arms had to be elastic, and moreover, the head had to be able to slide against the guides mounted on the wheel. The construction of the whole required a division of the coupling into three parts, corresponding to the three double arms that were adopted. The springs are secured in the annular pieces by wedges in such a manner that the tension of the wedges is further increased by centrifugal force. Furthermore, the plates are extended laterally within the hub, and are thus prevented from flying out. The hub-portions are of forged steel, of ample cross-section. The power is trans-

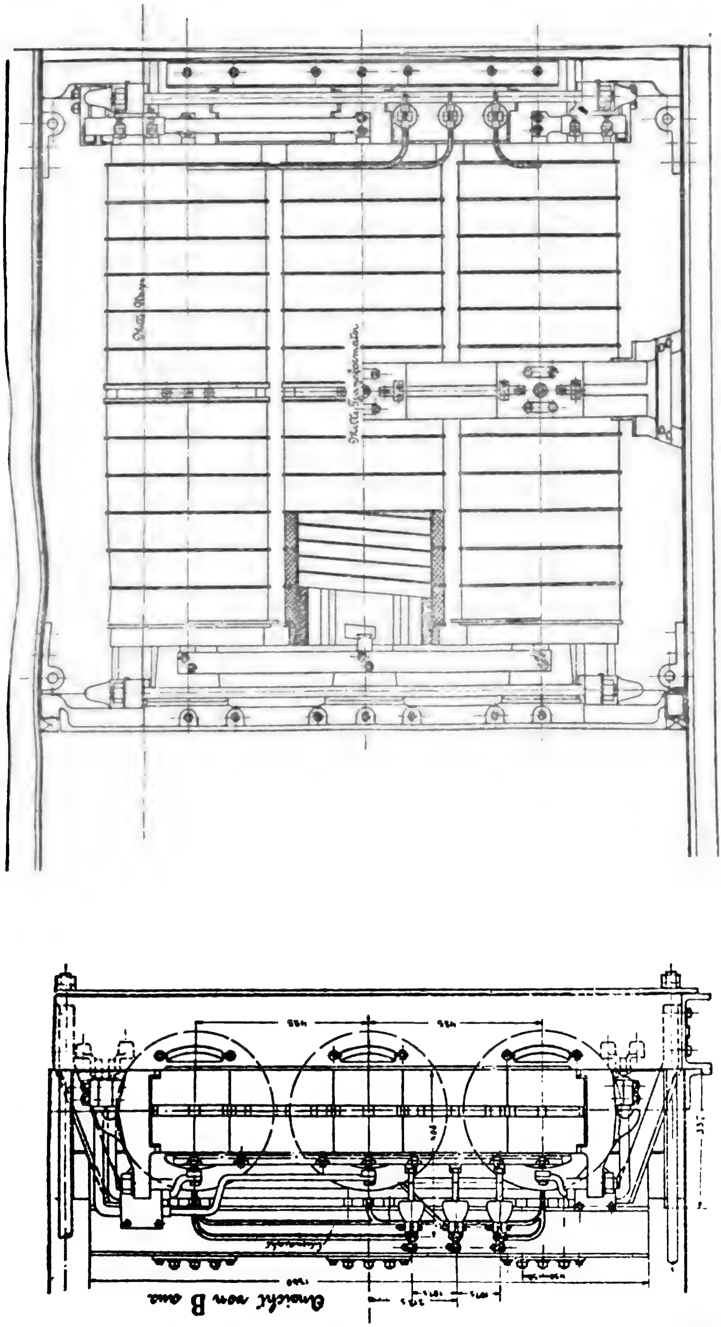


FIG. 28.

mitted by means of keys from the hollow shaft to the three-part hub of the coupling.

9.—TRANSFORMERS.

The three cores of the transformers (Fig. 28) are arranged side by side in accordance with the patents of the A. E. G. The axes of the cores run longitudinally in the car. The current transformation being from 12,000 volts to 435 volts, a massive copper spiral is used for the low-voltage winding, and the outer, or high-voltage winding, is separated from it by a micanite cylinder. A strong current of air passes through a longitudinal channel provided in each of the iron cores, and also through the space between the square cores and the round inner coil. As already mentioned, the air for this purpose is received through large air-holes in the roof and is delivered through air-ducts to the transformers. A protecting angle iron is provided on the roof for the removal of rain water, and before the air enters the shaft and the channels, it passes several times through wire netting, with wide meshes; the air is then conducted over the transformer and filtered again before entering the cores.

In spite of these precautions the air is only brought in direct contact with the interior of the cores of the transformer, and not with the parts carrying current. The cores are supported in the middle of their length to obviate any deformation due to the vibrations of the car. The transformer is suspended from the body of the car by draw bolts, so that the lateral sheets are only used for lining purposes, and are not called upon to carry any load. A further addition of springs connecting to the body of the car did not appear to be necessary, because the present arrangement is similar to that adopted for the International Sleeping Cars, and should suffice to ensure a long life for the insulating materials.

10.—CABLES.

The current is taken from each of the three-feeding wires by two trolley-bows in parallel. The upper part of each of these arms carries a number of aluminium rods, attached by means of narrow plate springs. The masses of the individual

rods must be sufficiently small to ensure that they bear constantly against the wire.

The head of the arm carrying the bow is pressed out of aluminium sheet, and is connected to the vertical base by rods, the base being mounted on ball bearings in the socket on the car. The bow is pressed against the wire by springs, the tension of which is regulated by means of cams. The current is carried by insulated leads from the head of the bracket to the foot of the arms that take the current, and is thence transmitted to the cables affixed to the roof of the car. The making or breaking of contact between the bows and the wires is effected from the interior of the car, so that the bows can be made dead before any person mounts to the roof.

All high-tension conductors (Fig. 29) were subjected to an insulation test of 20,000 volts; but notwithstanding this, they are placed on high-tension insulators, and are thus treated as if they were bare wires.

Safety fuses are fixed close to each bow; these operate as soon as contact is made from any cause between any phase and the earthed car, and the car is thus freed from current by the melting of the fuse. The wires of both collector systems lead from the safety fuses to the high tension cut-out. This cut-out is not requisite for controlling purposes, and serves merely to cut off the pressure at the end of the run. The switch may be operated from the apparatus compartment, or from either of the driver's platforms, so that it serves also as a safety switch in the event of the proper switch failing to act as the result of an accident.

The two branches of the current pass separately from this main switch to the transformers for each bogie. Each of these circuits and transformers is protected by fuses. The low-tension conductors lead from the transformers through a switching device to the motors. On account of the play to be allowed between the bogie and the car, owing to both the lateral oscillation when running round curves and the vertical deflection due to the action of the springs, the cables had to be suspended from flexible supports; this was effected by hanging them from a strong girth or belt. The cables leading from the motors back to the starting device are secured in a similar way.

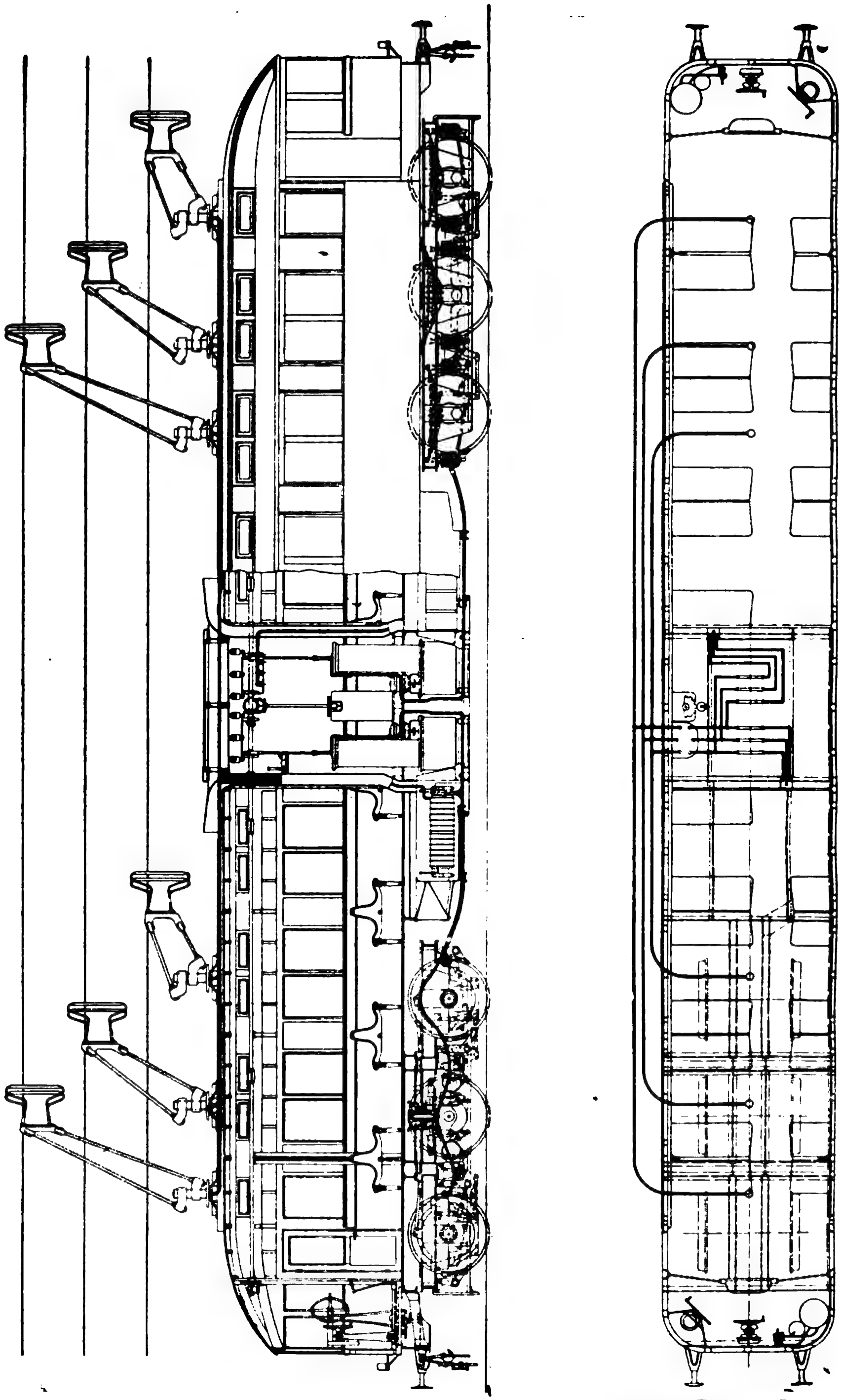


FIG. 29.

The switching device above referred to is used to switch on and off the current to the motors from the transformers, and it also allows of the adjustment for either direction of running or for the delivery of current for braking. Again, the storage battery is connected from this point to the stator circuit of the motors when braking the car as an automobile, *i.e.*, when braking independently of the overhead wire.

11.—Driving the Car.

The car driver has only to operate one single handwheel (Fig. 30), in order to carry out all the manipulations. By means of an indicator he can at any time ascertain the position of the apparatus, and by an amperemeter he ascertains the load on the motors; another apparatus continually indicates the speed of the car.

By the handwheel the driver operates a shaft extending through the entire length of the car. The switch is operated from this shaft by means of a pair of bevel wheels and cams. The movement of this cam-gearing to the extent of one tooth effects the switching of the controlling cylinder to current for running forwards or backwards, or for braking. The intermediate path which the cam or gearing has to traverse is used to operate the valve of the liquid starting-device, to which reference has been made in Part I. It may be repeated that the driver is in a position to regulate the speed of the car from rest to the full speed of the motors within suitable limits, and that he can also start or stop as quickly and as gently as may be desired. The liquid of the starting-device is fed continuously by means of a centrifugal pump through a cooling coil system (Fig. 4) through which a current of air continuously passes, and is thereby constantly mixed and cooled.

On the left of the driver is the handle for the operation of the compressed air-brake and, on his right, there is another, a hand wheel, for the hand-brake to be used in shunting. It is proposed to employ a number of different kinds of measuring apparatus on the trial trips, especially with the object of indicating the acceleration of the speed, of measuring the air resistance met with in head- and cross-

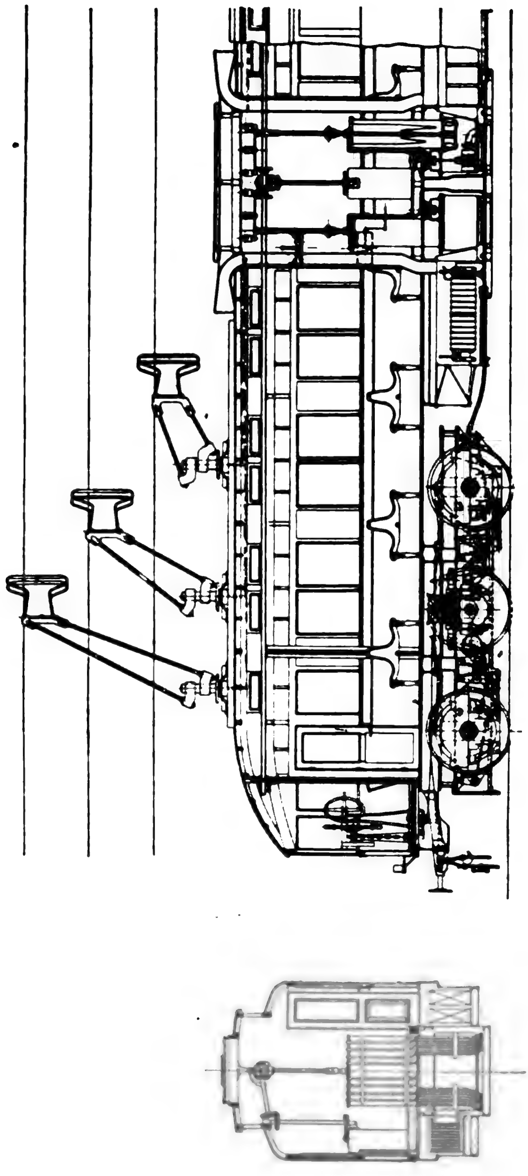


Fig. 30.

winds, and of measuring and registering the consumption of current.

12.—The Working Tests on the Trial Platform.

In view of the novelty of the entire construction and of almost every single part of the electrical equipment, and also of the great responsibility which the constructor had undertaken, it was deemed advisable to make the trial with the car at rest. The driving-wheels of one bogie were supported on rollers mounted on heavy cast-iron plates. In view of the maximum peripheral speed of 56 m. per second, the rollers were made of cast-steel, and the bearing rims were shaped to the profile of a rail-head. Wide plain rims were provided laterally to allow of a brake strap being applied, which, of course, like the rollers, had to be specially designed for the case in question. The latter were carried by means of strong axles in plummer-blocks provided with white-metal brasses. The speed of the rollers is 1,800 revolutions per minute. By this experimental arrangement, it was possible to run the motors of each single bogie up to full speed. The momentum required for testing the brake action of the motors and batteries was unfortunately wanting; and the small momentum of the motors and wheel sets could not furnish sufficient proof of efficiency; but, on the other hand, the results of the brake-action described in Section 4 were so highly satisfactory that there seemed to be no grounds for supposing that the system would prove to be otherwise than satisfactory.

The above statements give an outline of the method by which the designer solved the problem; and it may be added that the practical experiments on the trial platform gave very favourable results.

The great interest which experts throughout the world take in the development of the express railway has led to the publication of the above particulars. The question whether the speed aimed at will be fully attained depends only in part on the car itself and in part on the nature of the permanent way. A good deal of time is still

required in order to gain sufficient experience on this point, and also in regard to the consumption of power under varying conditions of work; and this brings us in the presence of a second problem to be solved.

There is already sufficient experience available as to many of the requirements and conditions of electrical traction as applied to long-distance working; and many a task, independently of whether low or higher speeds are concerned, can now be carried out without any difficulty.

The President.

The PRESIDENT: The subject dealt with by Herr Lasche is one of intense interest at the present moment. It is a subject which is occupying the minds of a great many eminent men, and it is a subject also which cannot have escaped the attention of our great railway companies. We are favoured this morning with the presence of Sir Wm. Preece, whose name has been associated very much of late with the introduction of electricity on railways, and I would like to ask him to be good enough to open the discussion on Herr Lasche's paper.

Sir Wm. Preece.

Sir WM. PREECE: I think that the electrical world of both hemispheres will feel deeply indebted to Mr. Rathenau and the Allgemeine Elektricitäts Gesellschaft for allowing Mr. Lasche to bring before us to-day such an admirable account of the experiments that are about to be conducted between Berlin and Zossen. I think we must all admire the candour, the openness, and the magnanimity with which the facts elicited by experiment have been brought before us. There is a very remarkable contrast shown in this paper between the ways of Germany and the ways of England. Here we find a magnificent experiment started and carried out at the instigation and under the eyes of the Emperor—a man whose far-seeing genius seems to be ever reading and ever studying and ever insisting on his countrymen doing all they can to place Germany at the head of the commercial nations.

Now a good deal of money has been expended in carrying out these experiments, and a good deal more money has been spent in this country in opposing experiments. We have been trying for some years past to induce the commercial and financial community of this country to find the money to establish a high-speed railway between Liverpool and Manchester, and, twice, Committees of the House of Parliament have affirmed the principle, that it is good and sound, and now, at last, we have power to carry out the experiment; but we are awaiting a German Emperor to find us the money.

There are a scientific way and a commercial way about our German friends that are sadly wanting with us. If I were to repeat here the rubbish that was given in the Committee-rooms of the House of Commons on this very question you would blush for your profession. I must confess that there is much satisfaction in finding that our German friends, who are the originators of the system, have adopted the three-phase system for high-speed working. I have myself long since come to the conclusion that it

Sir Wm. Preece.

is the only practical mode of supplying electrical traction to long railways. We in this country have not applied the tri-phase system so much as they have on the continent of Europe and in America. But the tri-phase system has advantages that commend it to the common sense of every engineer. In the first place, the tri-phase system, as carried out by the A. E. G. in these experiments, is a system that is more continuous in its action than a continuous current. Now that sounds rather anomalous, but the term "tri-phase" and the term "alternating current" are applied to electro-motive force and to the *current*. They are not applied to the *energy*. The energy is always positive, and if you take a tri-phase system and plot out an energy curve you will find that the energy curve is a sine curve without any amplitude. On the other hand, the positive energy curve of a tri-phase system is a straight line and a continuous system. So the torque of a tri-phase system is more continuous than that of a continuous current. We all know a continuous current to be pulsating, and every telephone man in this country knows that a tramway system such as they have in Glasgow or anywhere, if it disturbs the telephone disturbs it with a hum—the sound commencing with a low wail like that of a buffalo and ending in the scream of an agonised pig.

The tri-phase system has another great merit. It sweeps away your rotating machinery, in sub-stations. It sweeps away many parts that add weight to the machinery, and the result is that if you take the whole system of a railway company you will find that by using the tri-phase system you save at least 30 per cent. of the weight of your machinery, and I think a good deal more. In the next place, you are able to use high pressure, and by using 3,000 volts (they are trying 10,000 volts in Berlin) it enables you to fit up your line with one-sixth of the weight of copper; and, in addition to that, you are able to use or require for your sub-station purposes only one-fourth of the cost in buildings. So that when you take a line, and compare the cost of fitting up that line with the tri-phase system and with continuous current, you will find that you are with the former saving 40 per cent. at least of your capital expenditure.

Now Mr. Lasche has shown by his paper the practicability of this tri-phase system. He has shown how the comfort of passengers can be effected by the spring-bearing plans that we have seen before us.

I have just returned from Italy, where I have had the pleasure of seeing some trials on the Valtellina Railway carried out by Messrs. Ganz and Co. on this system. There they have not applied the same system as we have seen here to-day in transmitting power to the driving-wheel. This system we have seen here to-day is for high-speed working, whilst that used on the Italian line is for low-speed working. The energy is transmitted without any difficulty from a moving hollow axle by a link motion to the driving-wheels. The motion of the car is very smooth. It is one of the first and distinctive features of the system. The transition from the rattling, jerking, bustling, steam-rolled car to the soft, gentle electric car, although moving at a very good speed, is very marked. This spring bearing is undoubtedly a very good step in advance; like everything we have heard to-day. I think the

Sir Wm. Preece.

whole of us will watch with the greatest eagerness the progress made by our friends at Berlin, and as things of this kind are only anticipations of other favours to come, we sincerely hope that Mr. Rathenau will allow somebody to bring the subject before us after they have made some further trials. In the meantime I would beg distinctly to express the thanks of the whole electrical world to the "A. E. G." I think this paper is a paper based on broad principles. It ought to be above carping criticism, and I think, in carrying out the discussion, we should try as much as we possibly can to gloss over details, whatever we may think about them, and speak only on broad principles and the way in which those principles are being brought out by our German friends.

Director Rathenau.

Director E. RATHENAU (*Berlin*): I am somewhat at a loss to reply to the flattering expressions with which Sir William Preece had the kindness to honour my Company, but need hardly say that every person belonging to this organisation, proud of the testimony from such a prominent judge, would be happy if I thank him in his name.

The principle of laying before scientific and competent men the results of our studies, which we had occasion to demonstrate practically when you, gentlemen, visited our factories and electric works last summer, we shall not lose sight of in case the problem, of which Mr. Lasche has given you a brief account, turns out a success. It does not appear a wise policy to keep the results of our experiments on the line between Berlin and Zossen as the exclusive right and property of a few individual firms, but to communicate as much as possible to the engineering world in order to strengthen it for the serious struggle which is likely to arise from the competition between electricity and steam, and which must unite the forces, skill, and ingenuity of every engineer, if the introduction of electricity into railway service is not to remain solely a problem for many years to come. There is no doubt that the electrical industry has the greatest interest in the solution of this question, not because it would fill their large workshops with labour for a very long period—perhaps the whole century—but because electric locomotion will satisfy the demands of the public and railway companies far better than steam.

I am very well aware of the fact that competent railway engineers oppose, not without good reasons, this new mode of locomotion, but we must remember the difficulties which electricity had in fighting against gas; but as the millions of pounds now invested in electric lighting do not injure the interests of the gas companies and their shareholders, electromotion will act as a new lever in the development of railway traffic.

Sir William Preece made allusion to His Majesty our illustrious Emperor, the great patron of engineering work, who devotes his interest also to the progress of electricity. There is no doubt that the great work we have undertaken could not have been accomplished without the assistance of his Government, but nevertheless, I am convinced that your country, the birthplace of steam locomotion, will inaugurate electromotion in Europe, as, in Germany, railway lines are more or less a Government monopoly, and, for the introduction of electricity, competition is absolutely necessary, until this mode of

Director Rathenau.

traction has proved its superiority to steam in regard to economy also.

Sir W. Preece mentioned the Liverpool-Manchester line, which it has been intended to electrify for some time past: may I be allowed to say that my Company would be only too anxious to demonstrate the results of their experiments there, in case of such centres as these being obtainable.

Professor Thompson.

Professor S. P. THOMPSON: I think we may indeed congratulate ourselves that at this meeting of our Institution as a section of the Engineering Congress of Glasgow we have had produced such an epoch-making paper as this which Mr. Lasche has been good enough to prepare for us, and I would add my voice to that of Sir William Preece in expressing our great indebtedness to the "A. E. G." firm for having shown us so fully what they are at work upon, and how they have gone to work in the solving of this very important problem.

Sir William Preece has emphasised the very important step taken *in the promotion* of costly technical experiments of this kind, and the *fostering* of such experiments in Germany, and he has contrasted it with the waste of money on opposing experiments in this country. May I frankly, Sir William, be allowed to point out that you may spend money in right experiments, and in furthering them, and you may also spend money in opposing right experiments; but there is a third thing which sometimes happens, and which two years ago, when I had the honour of occupying this chair, I found it my duty to criticise, and that was the spending of money on trying the wrong experiment. For I then had to point out that the Directors of the Metropolitan District Company had appointed certain eminent engineers, and given them large funds to try an experiment near Earl's Court, and that the only experiment that was being tried there was an utterly unnecessary one; because we all knew that cars and trains could be moved by continuous-current motors taking current from a third rail, or from the lines, or from an overhead wire; and what was needed—the one experiment that we did want to see made—was to have three-phase tried on a large scale and for moving heavy trains; and that experiment was not tried, though £35,000 were available for the purpose. Now I ventured to criticise that, and, as Sir William Preece was one of those eminent engineers who were responsible for the wrong experiment being tried then, I naturally expected to have some kind of answer from him. Sir William Preece always has an answer ready, and he gave me privately one day the most complete and perfect answer to my criticism. When I repeated to him again my opinion that the wrong experiment had been tried, and that we had got no further from that expenditure at Earl's Court, "Oh," he said, "everybody knew we could move a train: the experiment was not to try a technical thing—to take us any further on the road as electrical engineers: the experiment was necessary to convince the Board of Directors. And it has had an admirable success." The experiment which, from a purely technical point of view, was a ghastly failure, was an entire and perfect success in convincing that Board of Railway Directors. Well, now we have had a different kind of experiment, and we have had the

Professor Thompson.

results, so far as they have yet gone, placed before us most admirably, and in such a way that the whole electrical world will be able to understand them and to take advantage of them. So I would re-echo what Director Rathenau has said—that it is the right and becoming thing for electrical engineers all over the world to put their forces together that we may have all possible light thrown upon this problem of heavy high-speed traction, that we may have the problem solved in as many ways as possible, and as soon as possible, by our combined efforts.

There are several interesting things in the detail of this paper which I would willingly ask you to spend a little time in discussing, but clearly we shall not have time to go into much detail. Two or three things at any rate are perfectly plain, or ought to be. The first is that for all this kind of work the day of the commutator is absolutely gone by. Any motor which requires a commutator on it, is simply useless on a high-speed line. It is an unnecessary and encumbering arrangement. If you look at the list of papers that are down for discussion by this section of the Congress, you will see that two of the most important of them are to deal with that still not altogether solved problem—How to get rid of the troubles induced in generators by the fact that when you generate a continuous current you still have to deal with that awkward commutator. Get rid of the commutator, as you must do for high-speed railways, and you will have no need to discuss the problems of commutation any longer. They will be ancient history.

The second point that comes very clearly forward is the advantage to be gained by introducing continuously varying resistances instead of step-by-step resistances by the employment of liquids. We know that the "A. E. G." is not the only firm--that there are other firms, and well-known firms, and admirable firms, that have found this out for other purposes—that there was a great advantage in using liquid resistances. The mere experiment, as it was ten years ago, of the laboratory, a thing that was laughed at in the electrical world as being impracticable—a liquid resistance for use in an electric circuit—is now an invaluable engineering appliance.

Further, there are some other details about the trucks, about the bearings, about the modes of reversing the direction, and change of phase in order to produce a breaking action, which would well deserve discussion from the technical point of view—I forebear to dwell upon them, because we have the much wider question before us.

May we not congratulate ourselves that a large and influential firm, perhaps the largest and most influential of the electrical firms on the Continent of Europe, has found it worth while to spend a large sum of money and to devote the energies of a large and highly trained technical department to the investigation of this practical problem? Here is a very important lesson for us in England. Where is the English firm which has got as large an experimental department, equipped as fully, on which it spends as much, in which it has employed so many very highly trained engineers? Until our manufacturers in England recognise that it is necessary to experiment

continuously, and to spend money, and to engage the best brains on experiments, they may expect to be forestalled by the firms of other nations. We must, if we would be in the forefront, continue to spend time and money and brains on keeping that place. We have heard from Mr. Lasche these numerous ingenious devices to meet point after point in the many technical problems that have presented themselves, and we recognise how costly such technical experiments must have been. We know that there are other firms on the Continent that are making similar sacrifices to progress, doing the same kind of thing in their own way, and that they are determined that they will not be behind the "A. E. G." in coming to the solution of similar problems. Where is the English firm which is doing anything of the same kind on anything like the same scale? We must not be left behind. The President of our Section put before you only yesterday another question from a national point of view; but surely this is just as important. The technical progress of the electrical industry demands *something* which, though it may look like a sacrifice, will in the long run be a great gain to the industry of this country. Professor Thompson.

Mr. A. SIEMENS: Perhaps I may take advantage of the presence of Director Rathenau, and assume once more my function as leader of the German trip, and thank Mr. Rathenau personally for all the kindness he showed us when we were in Berlin. He it was who originated the whole visit. He mentioned it first to our members when we were in Switzerland two years ago, and this year's visit is the result. Therefore I think we ought to express to him personally our great obligation. Mr. Siemens.

Now, as regards the paper, I think Sir William Preece was perfectly right to say that we ought only to discuss the general question and leave the details, which have been so admirably brought before us, *until they have* been actually tried. Because you must not forget that Mr. Lasche has told us the carriage has only been moved while stationary on movable supports, and the real experiment will take place in a few months' time, and there will not only be run this car which has been described to us, but also another car which has been built, and fulfils the same requirement, by the firm of Siemens and Halske. Herr W. von Siemens intended to be here, and he could have given us some details of their car, but he has been prevented, and I am not sufficiently *au fait* to give you any detail.

Now Professor Thompson has thought fit to flog the poor continuous-current motor. Well, I think it was at our International Meeting last year in Paris that it was brought out very clearly that continuous-current motors are in their proper place where you have frequent and great variations of speed, and that for any case where there is a long run at the same speed the three-phase currents are proper; and it goes without saying that for such high-speed railways the three-phase currents are the right thing.

The only general statement I do not quite agree with in the paper is on the second page. It says, "It must be remembered thaf money was not treated as the main consideration when electric light and electric power were introduced." Well, perhaps not. But we must

Mr Siemens. not forget that you cannot introduce anything which does not save money somewhere. If the electric light was not intrinsically cheaper than gas-light it had indirect advantages, otherwise it would never have been introduced. And it is the same here. We shall introduce these high-speed cars on the main lines of railways if they are cheaper, and if they are not cheaper they will not be introduced. And that is, of course, the great problem which is before us.

Then I differ from the author in so far as he thinks we can run these high-speed cars on the present railways. I am afraid if he has travelled on one or two of the lines from London to Glasgow on which the speed occasionally reaches eighty miles an hour, he will have felt the jerks quite badly enough. If you were going at a speed 50 per cent. higher I think the jerks would be dangerous.

But otherwise I certainly think that the paper is extremely instructive, and it is very kind of the "A. E. G." to have brought before us all these details.

Prof. Zipernowsky. Professor C. ZIPERNOWSKY (*Budapest*): I am not prepared to enter into the discussion on this very important subject, but I wish to call attention to one point:—Ten years ago, at the Frankfort Exhibition, I had the honour of giving a lecture upon the same subject. I showed also a carriage which it was intended to run between Budapest and Vienna. Ten years have since elapsed, and scarcely anything has been done, and I congratulate the "A. E. G.," and especially Mr. Lasche, on his having been able to make his excellent report, and with all my heart I wish the best success to this enterprise.

Herr Kolben. Herr E. KOLBEN (*Prague*): I propose to touch on the point that Mr. Alexander Siemens has raised as to the disadvantage of three-phase motors running at constant speed. We have seen by the explanations of Mr. Lasche, that he has been using exclusively resistances for regulating the speed of the three-phase motors, and it would seem as though in this respect the three-phase motor would be at a great disadvantage as compared with the continuous-current motor, which, as it is well known, is regulated as follows:—If two, or four, motors are on the car, they are connected either in series or in parallel, so that the speed can be reduced to half or even quarter-speed without any loss in resistances. Now I do not think that we shall remain at the present stage regulating the speed of the three-phase motor by resistances only; but, from my experiments and from my experience with cranework and hoisting machinery, I find we can reduce the speed by one-half (and even, if necessary, without any great complication by three-quarters) without any waste in resistance, by simply changing the number of poles—by merely changing the connections of the windings of the motor. This will be also the direction in which the experiments must be made in order to ensure a large measure of success in running large locomotives with motors aggregating 3,000 horse-power.

Mr. Kapp. Mr. GISBERT KAPP (*Berlin*): The question of high-speed railways has been on the *tapis* in Germany for some time. We have heard in Mr. Lasche's paper about the most recent and most perfect development of the car. Perhaps it will interest you to learn about the first car intended to work with three-phase current at 10,000 volts. About

18 months ago I had the good fortune to see that car and ride in it. It was really a locomotive, and was used on a small, very badly laid line in the neighbourhood of Berlin. The locomotive was made by the firm of Messrs. Siemens and Halske, of Berlin. I had at first some doubt as to the safety of working at 10,000 volts, but I can assure you that when I got on to that locomotive I had the feeling of perfect safety, and in this respect it was the ideal of an electrical plant. We are accustomed to see written up "Do not touch," or "It is dangerous to touch the wires." But to ensure safety by placards is not the right principle. I would like to have a plant where you could put up placards, "You may touch everything; it is perfectly safe." And this, in fact, was the case with that locomotive. The cab of the driver was in the middle of the locomotive, and consisted of an iron box with glass windows on all sides. All the ironwork and all the handles were earthed, and you could lean against the wall and you could touch anything without coming to harm. I wanted to point out that fact—the fact of the absolute electrical safety to the traveller in such a car, although it may be worked at 10,000 volts. Mr. Lasche has not spoken about that point, probably because he considered it a thing which was well understood. Nevertheless, I think it useful to draw your attention to the fact that already in the first car built by Messrs. Siemens and Halske the essential conditions of absolute safety from shocks has been fulfilled, and the same holds good for their latest car as also for the car described by the author. Mr Kapp.

An objection to the three-phase motor has been raised by Mr. Kolben, namely, that you cannot vary the speed without wasting electrical work in resistances. No doubt some waste is unavoidable, but this is also the case with continuous-current motors. But this waste is of no practical importance either in the one case or in the other. If you build a high-speed railway, do you think the driver is going to run slowly? He will go at the highest speed he can, and it will be a rare exception that he will have to run slowly by putting the resistance in action. It is true that by Mr. Lasche's arrangement of a liquid resistance the slow speed may be maintained for any length of time, and this is a great advantage, especially for mountain railways. Those of you who have seen the Jungfrau railway well know what it means to regulate by a solid resistance, and will appreciate the great improvement which Mr. Lasche has made. By this admirable device you have the possibility of starting up gently and, if need be, working the car any length of time at a low speed. But how often will such a need occur? We do not build a high-speed railway to run it slowly, and for this reason the time when the motor will have to work at a low efficiency will be as a rule very short—a few minutes in a run of hours. Therefore I do not think this objection to a three-phase motor—that it cannot work at a low speed—is an objection of any technical importance.

Professor H. S. CARHART (*Michigan*): It seems to me that the time is quickly coming when the electric companies and the public in the United States are likely to get back with good interest what they have contributed to the subject of electric locomotion. The conditions there Professor Carhart.

Professor Carhart.

are quite different from those prevailing in Europe, because so far the great manufacturing companies are kept busy in making machinery for ordinary low-speed locomotion. The building of short lines for suburban traffic is still incomplete, and we hear therefore nothing, except from abroad, about high-speed railways. I assure you that we are not at all ignorant of the experiments that are going forward in Germany, and I wish to add, on behalf of the electrical engineers of the United States, our thanks and appreciation of this paper which has been brought before us this morning. I may say only this, that while we are not engaged, so far as I know, in experiments in high-speed transmission, we are not entirely content with present plans. We have not yet reached standardisation; that is very certain, because the methods applied to electric railways are, in the United States even, in a state of flux at the present time. For example, we have a railway 40 miles long, running from the city where I live to Detroit, which is worked with direct-current from two stations. That railway is being extended 40 miles in the other direction, making a railway 80 miles long, and this extension necessitates the conversion from the direct current into a three-phase system with sub-stations and rotary converters. But, beyond this, I am personally informed by a friend of mine, who is an eminent engineer, that a new system will shortly be put into operation on a road in the State of Michigan. I am not at liberty to give details about it, on account of questions connected with patents, but I may say this—that this engineer proposes to introduce 10,000 volts directly into the car. And, furthermore, if I remember rightly, it is single-phase and not three-phase, though, so far as I can now see from the small number of details that I have examined, there is no reason why the three-phase should not be equally well used. I think I shall not be revealing any secrets when I say that this engineer has still another plan for getting round some of the difficulties of change of speed of the motor. In other words, I may just say that he proposes to keep the motor running at a constant speed while he changes the speed of the car when necessary, which is, I think, altogether a new problem.

Prof. Carus-Wilson.

Professor C. Carus-Wilson: I have been much struck, on hearing this paper read, with the immense amount of attention which has been given on scientific lines to working out every detail of this problem of high-speed railways, and I was surprised to hear from Herr Rathenau that Herr Lasche, who has had the organisation of the whole of this work, has not been occupied on it for more than nine months. The possibility of introducing high-speed railways into this country is attracting a good deal of attention at the present time. The principal difficulty is the question of curves. This has not been considered in the paper, because the railway upon which Herr Lasche's car is to run is practically a straight line. In this country it will be impossible to use the existing lines on account of their curvature. We shall have to construct special lines for the purpose, which shall be practically curveless. In view of this, great interest naturally attaches to the proposal that was brought before Parliament this year in the Mono-rail Bill. The essential feature of that proposal was that it claimed to provide a

Prof. Carus-Wilson.

method by which high speed could be obtained on curves of small radius. But the promoters of the Bill, instead of threshing out the whole problem experimentally beforehand, as our German friends are doing, came to Parliament and asked for powers to construct their railway, while all the technical problems vital to the success of the enterprise were yet unsolved. I do not think there is anything to commend that method. The lesson which we have to learn, and which has been impressed upon my mind on hearing this paper, is that every detail of a new system of this kind should be worked out with the greatest care experimentally. We are much indebted to Herr Lasche for showing us what are some of the actual difficulties met with in this problem, and we shall follow him with great interest in the experiments that he is now about to make.

Herr Lasche.

Herr O. Lasche (*in reply, communicated November 20, 1901*): Mr. Siemens appears to have misunderstood me. I did not intend to convey that a quick train service would be possible at a speed of 200 kilometres per hour on tracks as they are to-day, but only wished to state that with single electric motor cars the track and the bridges would be subjected to fewer strains than with trains and locomotives, and for this reason, without strengthening existing tracks, a considerably higher speed should be possible with electric cars than with steam locomotives, and therefore a quicker car-service could be maintained.

Mr. Kapp is correct in assuming that I thought it unnecessary to make special mention with regard to the safety of the passengers and driver from dangers arising from the high-pressure current. It will have been understood from the explanation in the paper of the arrangement of the apparatus and the method of running the cables in the car, that no difficulty has arisen in this respect.

The effect which curves will have on the running of cars at high speeds will be determined at the trials. The Berlin-Zossen line is not, as is apparently believed, quite straight, but has several curves, the smallest radius being 2,000 m. (100 chains). Other experience justifies the assumption that the firm guidance given to the wheels and the long three-axle bogie when passing over the curves will render safe and steady running possible.

The President.

The President: I am sure all here will agree with and thoroughly endorse the remarks of Sir Wm. Preece on the generous manner in which the Allgemeine Elektricitäts Gesellschaft have placed before the world the results of their experiments on this very important question of electric locomotion. At the same time what has been done only increases our desire for further information, and we shall be glad if Herr Rathenau and Herr Lasche will be good enough eventually to supplement the information which they have so generously afforded by communicating the results of the practical experiments as they are carried out.

Two speakers have expressed opinions as to the desirability of manufacturers contributing towards experimental trials on this subject. Well, it is to be hoped that such may be the case; but it also appears to me that the matter having been so fully brought forward as has been

The President. the case of late, that the railway companies themselves, seeing that their interest lies so much in that direction, might also take notice of the matter with a view to afford facilities for trying these experiments, and I venture to hope that what has passed here will come before them in that light.

I may perhaps be allowed to take advantage of this opportunity heartily to endorse the remarks of Mr. Alexander Siemens, in expressing the indebtedness of the Institution to Herr Rathenau and the Allgemeine Elektricitäts Gesellschaft, as well as to the several other companies, for the generous reception accorded and for the very great kindness shown to members of the Institution on the occasion of their recent visit to Berlin.

I have now to ask you to express in the usual manner your thanks to Herr Lasche and also to Herr Rathenau for this very delightful and most interesting paper.

The vote of thanks was passed by acclamation.

The PRESIDENT: I will now call upon Professor Andrew Jamieson for his paper on—

DANGERS FROM TROLLEY WIRES AND THEIR PREVENTION.

By Professor ANDREW JAMIESON, M.I.E.E.

I.—RECENT ACCIDENTS AND THE NECESSITY FOR THE PROPER PROTECTION OF TROLLEY WIRES FROM CONTACT WITH OTHER OVERHEAD CONDUCTORS.

Scarcely a week or even a day passes, that we do not notice in the public and the technical press, an account of one or more accidents, arising from the contact of overhead conductors with trolley wires. These accidents prove, that so long as telephone, telegraph, and electric light wires are permitted to cross over electric tramway routes, there is a liability to their occurrence; and further, that we still lack a perfect system of guarding trolley wires from accidental contact with other conductors. There is also the danger arising from the fracture of the trolley wire and its contact with persons or animals.

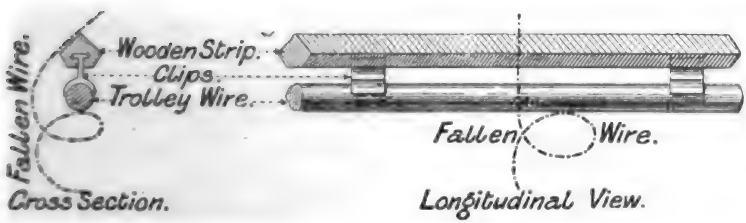
It will be still fresh in the memory of every one present, that about 7 p.m. on the 4th February of this year, a large number of telephone wires in Liverpool fell upon a trolley

line and resulted in the electrocution of two men and two horses, as well as the electrification and injury of a dozen persons. Further, on the 7th of February "a cluster of electric light wires in Princes Road, Liverpool, lodged on the tramway trolley wire, causing the breakage of the electric lamps in the vicinity." "On February 9th (in the same city) a trolley head fouled a span wire and broke it, so that it came into contact with the trolley wire and with the ground, thus causing alarm to the passengers and pedestrians, due to the heavy sparking and arcing."

It is needless for me to multiply these examples. Suffice it to say, that we have had in this city of Glasgow several instances of broken telephone and guard wires coming into contact with live trolley lines and producing alarming scintillations; although, fortunately, no fatal electrocutions have, so far, occurred from these causes. Many other electric tramway installations, however, both at home and abroad, supply sad instances of injury and even death.

II.—Methods which have been Adopted and Proposed for Protection against Contacts with Trolley Wires.

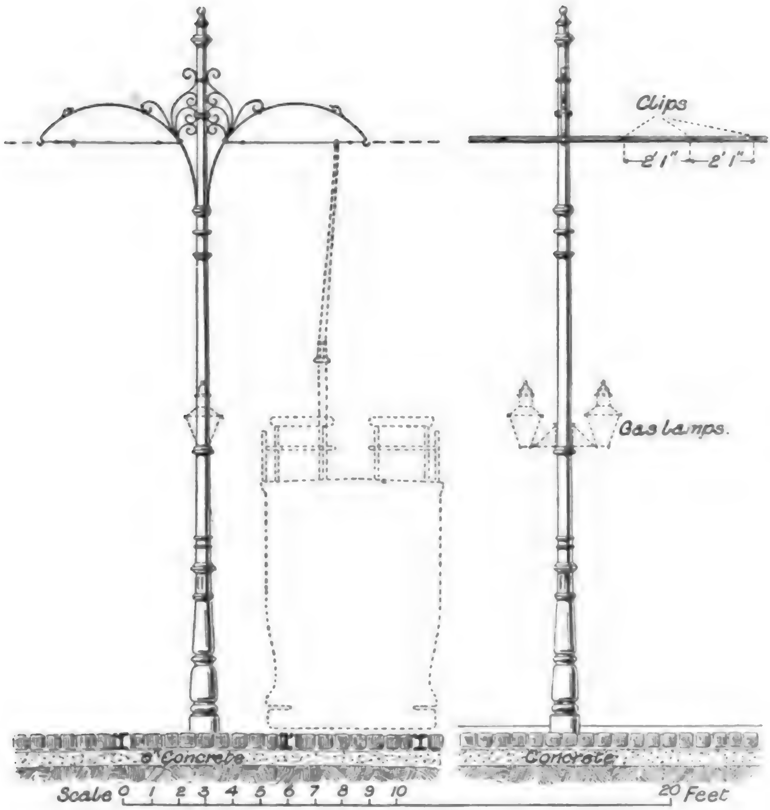
The form of guard adopted at Liverpool, Leeds, etc., with the view of preventing contact between the trolley wires and other broken or sagging conductors, is illustrated by Figs. 1*a*. It consists of strips of wood machined to the



Figs. 1*a*.—Guard System Hitherto Adopted at Liverpool and Leeds, etc

shape shown by the cross section and supported by brass distance pieces or clips which are soldered to the upper surface of the trolley wire at convenient intervals. Although one of the cheapest, and perhaps one of the least unsightly

forms in use, its inefficiency as a safeguard against fallen springy bronze telephone wires, was demonstrated by the Liverpool catastrophe. The dotted lines in the cross section and longitudinal view of the previous figures serve to indicate how the telephone wires curl and make contact with the trolley wire; or they may be dragged into connection therewith by a passing vehicle or car. In fact, to



FIGS. 1*b*.—Rails, Poles, Trolley and Guard Wires, with Outline of Lamps, Cars and their Special Road FENDERS as Adopted at Liverpool.

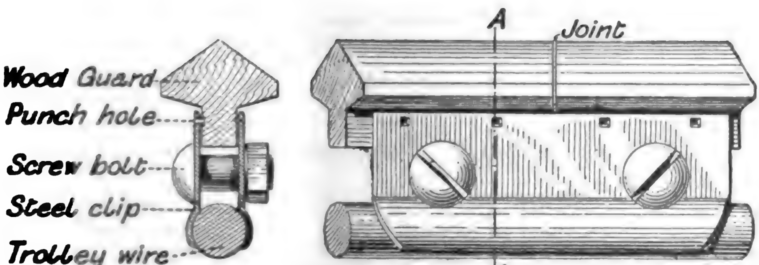
prevent the trolley wire current entering any of the fallen overhead conductors, the insulation resistance of the wooden strips would require to be great under all atmospheric conditions, the broken wires must clear the trolley wire and remain free until repaired. But such assumptions

are most unlikely of fulfilment in stormy or snowy weather and where there is considerable traffic.[1]

Figs. 2 and 3 show the two methods of arranging the guard wires which have been tried in Glasgow and many other installations. Wherever telephone or other wires are suspended above and across the trolley wires, each of the latter is guarded by *one* No. 7 S.W.G. galvanised steel wire, carried parallel to and about two feet above the live car wires. At first, these guard wires were insulated from earth and placed from eight inches to a foot to the left and right of the respective trolley wires. Now, however, they are earthed at the feeder pole of each half-mile section and placed for the most part vertically above the trolley wires which they are intended to protect, as in *Fig.* 3. But, as has been proved in actual practice, and as is shown by the dotted lines in Figs. 2 and 3, the fallen springy telephone wires do make contact, not only

[1] Since writing the foregoing part of this paper, I have received from Mr. C. R. Bellamy, the General Manager of the Liverpool Corporation Tramways, a description and drawings of the latest plan of supporting their "*wooden guard strips*." His drawings are reproduced in Figs. 1*b* and 1*c*, which are self-explanatory. The following is an extract from his letter of August 12th, 1901:—

"I have now the pleasure of sending you a drawing showing the details and method of protecting the trolley wires in Liverpool, by means of guard strips. In addition, I am sending you samples; *one* with a brass spring clip carrying a 'T' grooved, *wood strip*, and the *other*, which is the latest and best form, with a *steel clip piece*. In dealing with the subject, you will be pleased to know, that following the trouble we had in February last, we arranged with the Telephone Company to cable the whole of their wires crossing our trolley wires, and to place them underground by September, 1902. At this moment a great number of telephone wires have been placed underground, and none cross our trolley wires except by aerial cables. We have not yet finally arranged the matter with the



FIGS. 1*c*.—Guard System Now being Adopted at Liverpool.

Postal Authorities, but we are on the verge of a settlement. As a result of our experience during the past two years, we are strongly of opinion that overhead wires crossing trolley wires, must always be a source of danger, whatever may be the protective methods. We have therefore determined (as far as possible) to have them all cleared away."

with the guard, but also with the trolley wires. When the former were insulated, the current from the latter entered the fallen wires, and was therefore not only a great source of danger to passing human beings and animals, but has been known to set fire to telephone stations, wherein, there were either no protecting fuses or inefficient ones. When the guard wires are earthed, the short piece of contact-making fallen wire, is expected to melt almost instantaneously, and the street end thereof to fall harmlessly to the ground. This may happen without affecting the fuses or the automatic cut-out switches at the tramway sub- or main stations. In the case of a large number of overhead conductors, simultaneously making contact with the guard and the trolley wires, these safety devices are expected to

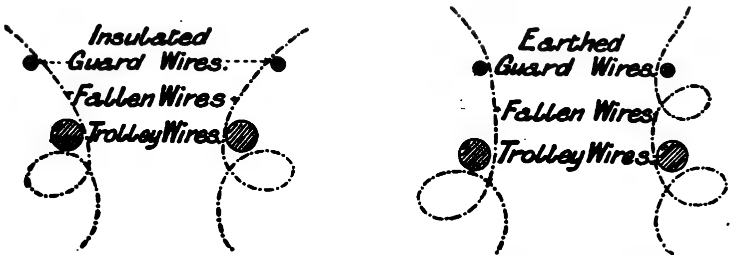


FIG. 2. FIG. 3.

FIGS. 2 and 3.—Guard Wires as Adopted at Glasgow and elsewhere.

act, and thus render the trolley wire of the section, neutral and harmless. Telegraph and tramway engineers hold somewhat opposite views, in regard to the advantages and safety arising from the insulating *versus* the earthing of guard wires, which will be referred to later in the paper.

III.—Board of Trade and Post Office Regulations.

In the Board of Trade "Electric Tramway Rules" which were issued in March, 1894, there are no regulations as to guard wires. In Form No. 2, revised and published by the Board of Trade in 1896, we find in Clause 22, the following statement, regarding crossing wires:—"Where an aërial line crosses or is in proximity to any metallic substance, precautions shall be taken by the undertakers against the possibility of the line coming into contact with

the metallic substance, or of the metallic substance coming into contact with the line by breakage or otherwise."[1]

The regulations by the Post Office authorities for telegraph and telephone wires crossing above trolley wires, prior to October 1901, have been as follows :—

(1). "When there is only a single trolley wire or two trolley wires not more than 12 inches apart, two guard wires should be erected as shown in Figs. 4 and 5.

(2). When trolley wires are more than twelve inches apart, and do not exceed 3 feet, the guard wires should be increased to *three* in number, as shown by Fig. 6.

(3). When the distance separating the trolley wires exceeds 3 feet, each wire should be separately guarded by two wires, as shown by Fig. 7."

FIG. 4.
One Trolley Wire.

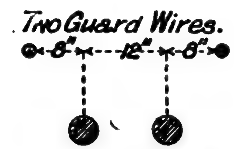


FIG. 5.—Two Trolley Wires.
Not over 12" apart.

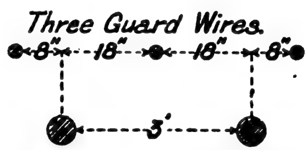


FIG. 6.—Two Trolley Wires.
Not over 3' apart.

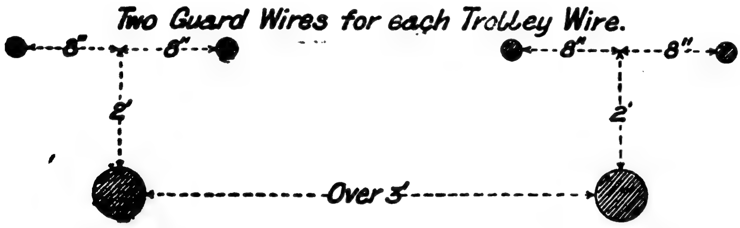


FIG. 7.—Two Trolley Wires. Over 3 feet apart.

FIGS. 4 TO 7.—ILLUSTRATING POST OFFICE REGULATIONS FOR GUARD WIRES.

If these Post Office regulations were faithfully and carefully carried out, there can be no doubt that the chances of broken telegraph or telephone wires coming

[1] Combined recent inspections have been made by the Post Office and the Board of Trade Electrical Engineers, with the view of formulating a joint set of rules. I have been promised copies of these before the reading of this paper. It is therefore likely that these special rules will be printed here in the Proceedings of this Institution.

into contact with the tramway trolley wires would be minimised. But tramway contractors and companies, or corporations as well as the general public, may be expected to object to the multiplicity of such wires so near the roadway, their liability to become inextricably mixed up in the case of an accident to one or more of them, and also on æsthetic grounds. I understand, however, that these regulations have been adopted in Bradford and other places.

As far as I am aware, the only place in Glasgow where cross-lacing or hammock-netting guard wires have been introduced (as proposed by the Post Office) between the overhead telegraph or telephone lines and the trolley wires, is at Langside Road, where the afore-mentioned protections are considered inadequate.[1]

IV.—Contacts Between and the Breaking of Guard and Trolley Wires.

The chief and the primary causes of such contacts and breakages arise from :—

(1). The omission to turn the trolley-pole at the end of a tramcar line in the proper slanting direction for the return journey, or whenever the direction of the propulsion of a car has to be reversed. The neglect of this precaution often unships the trolley-pole from the trolley wire, and permits the former to foul the guard wire or its cross street span wire, thus severing the binding between the latter two wires, or breaking either or both of them.

(2). Unshipment of the trolley pulley at street corners where the ears are too short, or the frogs and the cast bronze (**Y**) or (**+**) brackets at crossings, are badly adjusted.

(3). Disconnection between the trolley wire from hangers, splicing ears, or sectional insulators due to their imperfect soldering and clipping. The breaking of the trolley wire at the pinching pins of bracket crossings, or at section insulators and ears, due to overheating when soldering.

[1] The author has to thank Mr. J. Gavey, Assistant Engineer-in-Chief of the Postal Telegraphs, and Mr. W. A. Valentine, Glasgow District Manager of The National Telephone Company, for the specimens of telegraph and telephone wires and cables submitted to the meeting.

(4). Fusing of the trolley wire due to intermittent contact and arcing between it and a disconnected guard or span wire.[1]

Since the guard wires are generally made of but *one* No. 7 S.W.G. galvanised steel wire (of ·18″ diameter, having a breaking stress of less than 2,000 lbs.), whereas, the cross-street spans for the guard wires are composed of seven-strand galvanised steel wires (each wire of which is No. 14 S.W.G. of ·08″ diameter, with a combined breaking stress of over 3,500 lbs. for the complete strand), the chances are, that either the guard wire or its weak binding to the span wire is broken. Then, the guard wire falls into contact with the trolley wire. If the former be *insulated* and originally fixed about 2 feet above and some 8 inches to 1 foot to the right or left of the trolley wire, it has the chance of falling clear of the same. The current may then be switched off at the nearest street pillar-box from the half-mile section in which the mishap took place, and the guard wire refixed without causing any damage. If, however, the guard wire should be earthed, either at the centre, or the ends of its half-mile section, or preferably at several pole-points along the same, and if it be originally supported vertically above its trolley wire, then it naturally falls upon the latter, and the current *therefrom* enters the former and causes delay and trouble.[2]

When the guard wire is only earthed at each end of a half-mile section, and contact takes place between it and the trolley wire (say about the centre of this section), then the joint resistance of the contact and the two quarter-mile lengths of guard wire may be so great, that the current passing through the contact does not increase the normal trolley wire current, by an amount sufficient to blow the nearest station fuses (if there are any), or to free the automatic cut-out.

[1] See Appendix, Table I., for sizes and tests of these wires. The tables were kindly supplied to the author through Mr. John Young, the General Manager of the Glasgow Corporation Tramways. The author has also to thank Mr. Young and Mr. Clark, the Chief Engineer of the Glasgow Tramways, for the numerous specimens of trolley, guard, span, and pull-off wires, as well as ears, insulators, and other overhead fittings, which are now placed before the members.

[2] The guard wires are bound firmly to the cross street span wires, and these are connected to the cast-iron pillars (or house brackets); the latter should be bonded to the tramway rails in order to ensure a good "Earth" or "Return Circuit."

I am of the opinion, that guard wires and their bindings should be made of mild silicon bronze, instead of the usual galvanised steel. These would be stronger for the same size, and would not only have greater conductivity, but they would withstand the rapid, corrosive effect, which grimy chemical-laden atmospheres have upon galvanised steel wires.

It is seldom that the trolley wires break from over-tension arising from mal-erection, or even from fouling the trolley poles. They are usually composed of the very best hard-drawn 98 per cent. conductivity copper, having a diameter of ·37″, which is equivalent to No. 3/0 S.W.G. or fully 00 B. and S. gauge. The initial stress which this wire will withstand before beginning to stretch is over 54,000 lbs., or 24 tons per square inch of the full section. But, when subjected to a continuous steady pull, the very small elongation of 4 per cent. is accompanied by a gradual diminution of the original cross area of fully 40 per cent.[1] In any case, there is comparatively little chance of the trolley wire being broken by an accidental stress, except where it becomes rapidly worn at sharp street curves. Special watchfulness is therefore necessary at such curves, in order that the copper wires may be renewed before they become unduly reduced in size.

V.—Freeing, Earthing, and other Safety Devices.

Even assuming that the trolley and guard wires are made of the best materials and have been erected in the most substantial manner; further, that the former is divided into separate half-mile sections, of which as few as may be practicable are supplied with current from the power-house or sub-station by any single "feeder"; it is, nevertheless necessary, to be able to render any section inoperative or "dead" as soon as possible after any one or other of the previously mentioned faults occur therein. Many devices have been proposed and adopted with this object in view, of which the following may be mentioned:—

(1). Fuses and automatic cut-out switches at the supply stations. But, as we have already stated, these do not always act unless an abnormal current is demanded by a "short circuit" to "earth," or to the "return" conductor.

[1] See Appendix, Table I.

(2). Fuses or automatic[1] cut-out switches, or simply hand-switches, in each of the half-mile street pillar switch-boxes. There should also be a telephone, or a connection for one, in each of these boxes, in order to be able to communicate direct to the current supply stations and the engineer's office. It is unusual to place either fuses or even automatic switches in these pillar boxes, for most tramway engineers object to multiplying such devices. They therefore simply insert therein, a main feeder hand-switch and a trolley wire section hand-switch for each car line, plus a telephone wire connection. Moreover, keys for opening these boxes are (as a rule) only given to the engineering staff, and consequently neither the car driver, nor the conductor, nor the car inspectors can operate these switches in case of an accident to any particular section. All that they can do under the circumstances, is to use their insulating gloves and pliers, or earth a fallen wire to the rails and communicate with the head office from the nearest special telephone pillar. This roundabout proceeding causes an unnecessary waste of time and blocking of the traffic, as well as a possible cause of danger to passengers. Why not supply these employés with keys, and give each of them clear printed instructions how to act under certain circumstances?

(3). Blackwell and Co.'s "Earthing Device" is attached to either a bracket arm or a trolley wire suspension, and it acts when the trolley wire breaks, by mechanically short-circuiting it to the rails.[2]

(4). Placing an earthing switch in each car. In the case of the severance or disconnection of a trolley wire, or a serious downfall of overhead conductors, all that the driver or the guard has to do, is to break the glass front of a special box and turn a switch or insert a plug into a metal hole, thus immediately earthing the trolley wire to the tramway rails through the trolley pole and car wheels. This operation

[1] See *The Light Railway and Tramway Journal* of July 5th, 1901, pp. 32, 33 and 42, for descriptions and illustrations of Quin's safety switch; also *The Railway and Tramway World* of July 11th, 1901, for Mr. Manville's paper on this subject. A specimen of Quin's safety switch together with drawings were placed before the members. These switches and drawings were sent by the British Insulated Wire Company, Ltd., who are the sole makers.

[2] For illustrations and descriptions see the periodicals referred to in the previous foot-note. Specimens of Blackwell and Co.'s "Earthing Devices" were placed before the members.

instantly causes an abnormal current to flow in the feeder to the section in which the car happens to be at the time, and consequently blows its safety fuse or frees its automatic switch at the station. This device, which is being tried in Leeds, seems to me to be one of the simplest and most direct methods of rendering a section neutral in the case of an emergency. The attendant at the station should be authorised to close the freed automatic circuit-breaker, three successive times; when, should it persistently and immediately fly out again, he must attend to the telephone for instructions before again closing the switch.

(5). Roofs to upper deck cars (like those at Cape Town, South Africa) to prevent sagging or broken trolley and guard wires coming into contact with their passengers.

VI.—Aërial Telephone and Telegraph Cables versus Underground Wires or Cables.

In Glasgow there are now three authorities dealing with these important matters, viz :—

(1). The Government Postal Engineering Department, who have placed their principal telegraph and telephone city wires underground, but who have still a large number of ærial wires.

(2). The National Telephone Company, who have hitherto carried their fine bronze wires overhead, and who, being prevented from opening the streets, are now running aerial telephone cables. These consist of about 100 paper-insulated wires, twisted together and then insulated as a whole with canvas and vulcanised india-rubber, protected by waterproof matting and strong woven tape. These cables are suspended by hooks hung from strong stranded steel span wires, attached to brackets, fixed to the walls or the roofs of buildings. Two conductors are used for each closed telephone circuit to avoid induction, etc. Such cables and their suspension spans are not likely to interfere with tramway trolley wires; and even if they did come down in the case of a fire, they are so large, well insulated and strong, that they could be more readily dealt with, than a similar number of bare bronze springy wires.

(3). We have the Corporation of Glasgow, who have just started a Telephone Exchange, and who, having full

authority in regard to their streets, have very properly taken the precaution to place all their city wires and cables in underground cast-iron pipes, where they approach the tramway lines.

There cannot be the slightest doubt, that the only sure and safe plan, is to place all non-tramway electrical conductors of whatever kind underground. If this were done, then there would be no necessity for guard wires, thereby leaving the trolley wires free from extraneous contacts, and minimising the afore-mentioned dangers.

APPENDIX.

TABLE I.—TESTS OF TROLLEY, SPAN AND GUARD WIRES FOR GLASGOW CORPORATION TRAMWAYS.

BY THE STEEL COMPANY OF SCOTLAND, LIMITED.
HALLSIDE WORKS, 30*th day of August*, 1900.

Samples.	Diam. Ins.	Actual Stress.			Breaking Stress.	Initial Stress.	Exten. per cent. in 8″.	Size of Fracture.		Per cent.
		Area. Sq. in.	Tons.	Lbs.	Tons per sq. in.	Lbs. per sq. in.		Dm. ins.	Area sq. in.	
Cold Drawn Copper Trolley Wire. 3/0 S.W.G.	·37	·1075	2·6	5824	24·2	54,200	4·0	·24	·0452	57·9
Trolley Span Wire, Galvanised Steel of 7 strands. Each wire No. 12 S.W.G. ...	·105	·0606	2·15	4816	35·5	79,500	—	—	—	—
Guard Span Wire, Galvanised Steel of 7 strands. Each wire No. 14 S.W.G. ...	·085	·0397	1·60	3584	40·3	90,200	—	—	—	—
Guard Wire, one No. 7 S.W.G. Galvanised Steel	·180	·0253	0·85	1904	33·6	75,200	15·0	·12	·0113	55·3

TABLE II.—ANALYSIS OF THREE SAMPLES OF COPPER ALLOY* FOR "EARS" AND "PULL OFFS."

CHEMICAL DEPARTMENT, *October 5th*, 1900.

	Straight Line Ear.	Guard Double Pull Off.	Trolley Single Pull Off.
Copper	88·54	85·84	85·84 per cent.
Tin...	7·79	4·57	8·73 " "
Lead	0·75	2·86	0·72 " "
Zinc	—	6·24	4·13 " "

* These fittings are generally made of "Admiralty Mixture."

TEST III.

Tensile Test of "Dirig's" Globe Strain. (Insulation green colour.)

The first perceptible extension was noticed when the tensile stress reached 2·5 *tons* (5,600 *lbs.*), while the composition slightly cracked. The specimen broke through bottom eye at the maximum stress of 2·9 *tons* (6,496 *lbs.*), while the original crack in the composition widened.

TEST IV.

Tensile Tests of two Brooklyn Strain Insulators. (Composition red colour.)

The large one broke through large eye after a stress of 3·3 *tons* (7,392 *lbs.*) was reached. ***The small one*** broke through large eye after a stress of 2·2 tons (4,928 lbs.) was reached. The composition did not show signs of cracking in either case.

TEST V.

Tensile Test of Double Pull Off. (Composition green colour.)

First perceptible extension observed when the tensile stress reached ·07 tons (156·8 lbs.). Insulated bolt became fast at 1·1 tons (2,464 lbs.), ruptured through one arm at a stress of 1·9 tons (4,256 lbs.).

Original distance between centres of eye-holes 6 in., extended ¼ inch when bolt became fast. Total extension at rupture, 2 inches. Composition intact.

TEST VI.

Tensile Test of Single Pull Off. (Composition green colour.)

The first perceptible extension showed at a stress of ·09 tons (2,016 lbs.). Insulated bolt began to bend at 1·2 tons (2,688 lbs.) and centre of bolt to centre of eye-hole extended 1 in. Final rupture at 1·9 tons (4,256 lbs.).

TEST VII.

Compression Test on Single Pull Off Insulated Bolt. (Red colour.)

Original diameter 1·18 inches, slightly tapered.

At 4 tons (8,960 lbs.) very slight cracks observable in composition.
„ 6 „ (13,440 lbs.) diameter or deflection stood at 1·17 inches.
„ 10 „ (22,400 lbs.) „ „ „ 1·165 „
„ 11 „ (24,640 lbs.) „ „ „ 1·15 „
„ 11½ „ (25,760 lbs.) badly cracked.

TEST VIII.

Compression Test on Single Pull Off Insulated Bolt. (Green colour.)

Original diameter 1·18 inches, slightly tapered.

At 4 tons (8,960 lbs.) showed very slight cracks.
„ 6 „ (13,440 lbs.) diameter or deflection was 1·17 inches.
„ 8 „ (17,920 lbs.) „ „ „ 1·16 „
Cracks in composition gradually extended as weight was applied, until at 8 tons (17,920 lbs.) it was badly cracked.

TEST IX.

Tensile Test of Ear with Insulated Bolt screwed in. (Green colour.)

After gradually applying the stress up to 2 tons (4,480 lbs.) the composition came off head of bolt. The ear collapsed on both sides of screwed neck when the stress reached 4·6 tons (10,304 lbs.).

Mr. M. B. FIELD: The subject of the dangers which arise from overhead telegraph and telephone wires when erected in the vicinity of electric tramways operated on the trolley-wire system is one of great importance at the present moment, and this paper will be of especial value if it be the cause, in any way whatever, of the removal of these unsightly and dangerous telegraph and telephone wires. Mr. Field.

Professor Jamieson talks about the dangers arising from overhead trolley wires, and their prevention; to be accurate he should speak of the dangers accruing from the overhead telegraph and telephone wires, since it is these that break, and by so doing introduce the dangers referred to in the paper before us. Now these dangers might perfectly well be obviated if the *proper* regulations were formulated and enforced; I mean regulations as to the maximum length

Mr. Field. of span permissible for overhead telegraph and telephone wires, and methods of crossing trolley wires. The reason why no such regulations exist at the present time is, I think, easy to see; it is because the advent of the telegraph and telephone was prior to that of the electric tramway.

Hitherto it has been the custom of the telegraph and telephone authorities to erect their wires overhead with far longer spans than can be considered safe from an engineering point of view. The reason for this has been partly, no doubt, to save expensive supports attached to the roofs of houses, and partly on account of the difficulty experienced in obtaining the necessary wayleaves. Moreover, in times past the breakage of a wire here or there has not been attended with any very great danger, and with the exception of the relatively small inconvenience of interrupted communication along that particular line, no serious consequences have been the result of such a breakage. Hence it is that what we should call a lack of good engineering on the part of these authorities has been tolerated up to the present, and no questions asked. As soon, however, as an electric tramway is operated in the vicinity of such wires, the possibility of a breakage of the same is fraught with very considerable danger to the public. The consequence is that the Board of Trade steps in, and instead of striking at the root of the evil, and insisting that the telegraph and telephone wires shall be so erected that they shall not be continually breaking, it devises a special system of guard wires—in itself a new danger, which under certain circumstances is almost as great as the old that it seeks to obviate—and forces the tramway authorities to adopt it.

In other words, the Board of Trade, in attempting to remedy one evil introduces a new one, and in so doing throws the whole onus of the bad engineering of the telegraph and telephone authorities on the shoulders of the tramway undertaking.

There are places in Glasgow where from six to ten consecutive spans of trolley wire run parallel with single spans of telegraph or telephone wire. Again, telegraph or telephone wires often cross tramway routes at such narrow angles, that spans of 300 to 400 feet or even more are necessitated between the support on the one side and that on the other side of the street. In such cases by crossing sharply at right angles, spans of not more than 100 or 120 feet would be required.

I do not propose here to formulate regulations which would ensure against the breakage of telegraph and telephone wires in the neighbourhood of trolley wires, but it must be patent to all that at such places where these crossings occur it is quite possible to work with spans not exceeding the above limits, or to cable the wires and suspend them from steel ropes as is being done now by most of the railway authorities in this neighbourhood where their telegraph wires cross the tramway trolley wires.

M. Gerard. Mons. Ernest Gerard (*Brussels*): It is very difficult to speak about this very delicate matter because of the conflict between private interest and public safety, and I am not sufficiently acquainted with the English language to speak about matters of policy. Technical matters are very much more easy to speak of in a public assembly because we

M. Gerard. are acquainted with them by lectures, and in this matter Professor Jamieson very cleverly describes all the existing systems and finally proposes what he esteems to be the right one. As an engineer I should be disposed to agree with his conclusions, but as an official I cannot be so decided in my remarks, so far as a theoretical opinion could be assumed as the basis of a government rule. There is, of course, no system which is absolutely safe; but I should have liked to ask Professor Jamieson if among the systems which he has described there is one which he condemns absolutely? His opinion in that matter would be of great value to me.

Mr. Blackburn. Mr. G. R. Blackburn (*communicated*): Whilst fully agreeing as to the necessity for doing away with overhead telephone and telegraph wires, it must not be overlooked that in most large cities it is a work of time and involves great expense. In the meantime some form of guard is absolutely necessary. I entirely concur with the author as to the inefficiency, and even danger, of guard-strip in whatever manner it may be fastened to the trolley wire. Its inefficiency was recently very plainly proved in the case of the Liverpool fatal accident. It has been tried in Bradford, and totally abandoned owing primarily to the following causes:—(1) Danger from telephone wires curling underneath trolley wire. (2) Difficulty of securely fixing it. (3) Impossibility of keeping the insulation resistance good.

Probably the most efficient safeguard at present is *earthed* guard wire put up in accordance with Post Office Regulations as referred to by Professor Jamieson. This arrangement is the one carried out in Bradford and other cities, and when efficiently earthed (say at every third or fourth pole) has been found to be by far the most satisfactory method. Guard-wires to be of any use, however, must, in my opinion, be well earthed through a low resistance path, otherwise in the case of a wire breaking and falling on the trolley, the resulting current would be insufficient to release the station automatic switch.

With regard to the Post Office proposal to use hammock netting guard wire, I can only say that in the event of a trolley leaving the wire (a not uncommon occurrence), either the trolley head would be pulled off or the netting would be wrecked unless placed at a considerable height above the trolley. In any case its use seems undesirable.

As to the use of silicon bronze for guard wires, I do not see any reason why it should not be perfectly satisfactory. It certainly has many advantages to commend it.

The use at the power-station of automatic switches which can be regulated to act when an abnormal current passes is quite the usual thing, and they can be depended upon to act promptly if the fallen wire is well earthed. Hence the importance of earthing guard wires at very frequent intervals. Section boxes should be as simple as possible, and only contain the lightning arrester, main feeder switches, and a switch for each trolley wire section, and perhaps in addition a telephone connection. Using a box of this type there can be no possible objection to allowing drivers, inspectors, and other officials to carry a box key for use in cases of emergency. In the case of Bradford, and I believe several other places, all drivers, inspectors, motormen, and in fact nearly all

Mr. Blackburn.

employés are provided with a key and have instructions to pull out *all* switches in the box in the event of a breakdown of the overhead equipment. There is thus no possibility of confusion as to which switch should be pulled out. No trouble has been found to arise in the working of this arrangement, and the delay to traffic is very much lessened by every man being in possession of a key.

Each car on the Bradford system has lately been fitted with an earthing switch similar to the one described by Prof. Jamieson in his paper. On breaking the glass of this switch the trolley wire is automatically earthed, and an enormous current then flows making it impossible to keep in the automatic switch at the power-station. Consequently the line is made "dead" and all danger from a fallen wire obviated at once. This switch is, in my opinion, the most efficient way of making a line "dead," and has, when under trial, proved very satisfactory.

The next best thing to putting telephone wires underground is to run them in an aërial cable as is now so often done. Finally, I entirely agree with the author's statement that the only real safeguard is to place all telephone, telegraph, and electric light wires underground.

The President.

The President: I should like to ask if there is any one here representing the Telephone Company? The suggestions which have been thrown out by Professor Jamieson in his paper will, I have no doubt, receive the consideration of the Tramway Companies. As the time is so short, and we have two other papers to deal with, I will ask Professor Jamieson to be good enough to render his reply in writing.

Professor Jamieson.

Professor Jamieson (*in reply*):—I thoroughly agree with the greater part of Mr. Field's remarks, but I do object to the statement at the beginning of his second paragraph, wherein he says:—"Professor Jamieson talks about the dangers arising from *overhead* trolley-wires, and their prevention; to be accurate, he should speak of the dangers accruing from the overhead telegraph and telephone-wires, since it is these that break and by so doing, introduce the dangers referred to in the paper before us." The word *overhead*, as applied to "trolley-wires," is not used in *any* part of my paper, since it would be superfluous in the present case. Besides which, trolley-wires do sometimes break or become disconnected quite independently of any effects from overhead conductors—as stated in Part IV. of the paper. Moreover, Divisions I., II., and III., deal directly and explicitly with dangers accruing from the overhead telegraph and telephone-wires. However, I suppose his statement just amounts to this, that the short title of the paper did not fully convey to city tramway electrical engineers, the fundamental causes of the dangers? Yet, I think, that in the third paragraph of his remarks, his argument is all in favour of the present title. For, he says, "Moreover, in times past, the breakage of a wire here or there has not been attended with any very great danger, and . . . . . . no serious consequences have been the result of such a breakage."

In support of Mr. Field's further remarks, I herewith introduce two figures, from recent photographs, which show by no means the worst conditions, as to the number, length of span, or acute angles of aërial conductors crossing over tramway routes in Glasgow! (Figs. A and B.)

Telegraph and telephone aërial conductors have increased so

From photographs] [*by W. J. Hassard, Glasgow.*

FIGS. A AND B.

Telegraph and Telephone Wires, crossing over busy Electric Tramway Routes, in Glasgow, November, 1901.

Professor Jamieson.

gradually, and existed so long in our cities, without causing serious mishaps to the public (prior to the sudden introduction of the trolley-wires), that the British Government (to whom most of these belong or pay royalty), have no doubt felt unwilling to apply such stringent rules as they did in the case of "Overhead Electric Light and Power Wires," and are now doing with Electric Tramway Conductors.[1] Nevertheless, as Mr. Field says in his fourth paragraph, "The Board of Trade, in attempting to remedy one evil, introduce a new one. . . . . ."

I quite appreciate the difficulty of Monsieur E. Gerard, when speaking about this delicate matter; for, as Engineer-in-Chief to the Belgian Ministry, for the railways, posts, and telegraphs, which belong to his Government, he has no doubt to be very careful in expressing his opinion regarding the precautions which should be adopted at Brussels, and other places, where tramway companies are working the trolley-wire system.

Being free to express my own opinion, I most decidedly say, that if his Government is to retain their own as well as any private aërial telegraph and telephone lines, crossing trolley-wire routes; then, in the interests of the former, I *absolutely condemn* bare metal guard-wires which are insulated from earth, at their fastenings. I do so, because, whenever a telegraph or telephone-wire breaks and falls across these bare guard-wires, and at the same time makes contact with a "live" trolley-wire; then an electric current at the full voltage of the trolley-wire enters the telegraph or telephone wire. This current at once "blows" their fuses, if there are any. If there are no such fuses, then it spoils the instruments at the sending or receiving ends, and perhaps at both of these. It may even set fire to the houses containing them; for I understand this happened not very long ago at Zurich and elsewhere. Even if there are fuses, the instruments may be damaged and an attendant receive a shock before these cut-outs have time to operate. Whereas, with thoroughly well-earthed guard-wires (*i.e.*, earthed at frequent intervals along their lengths), these dangers are minimised, as explained near the end of Part II. of my paper.[2]

[1] *See* Munro & Jamieson's, Pocket Book of Electrical Rules and Tables, 15th Edition, page 568, *re* "Board of Trade Rules for Overhead Electric Light or Power Wires. (1888 Act)." The following are examples :—

Rule 2: Maximum Intervals between Supports.—Every aërial conductor shall be attached to supports at intervals not exceeding 200 feet where the direction of the conductor is straight, or 150 feet where this direction is curved, or where the conductor makes a horizontal angle at the point of support.

Rule 6: Angle of Crossing Thoroughfares.—Where any conductor crosses a street, the angle between such conductor and the direction of the street at the place of such crossing shall not be less than 60 degrees, and the spans shall be as short as possible.

Rule 7: Crossing Other Wires.—Where any aërial conductor is erected so as to cross any other aërial conductor, or any suspended wire used for purposes other than the supply of energy, precautions shall be taken by the owners of such crossing conductor against the possibility of that conductor coming into contact with the other conductor or wire, or of such other conductor or wire coming into contact with such crossing conductor by breakage or otherwise.

[2] M. Gerard and others, should see the *Electrical Review*, of London, September 27th, 1901, pp. 502 and 503, for a description with two illustrations

Professor Jamieson.

For a similar reason, I condemn the "Wooden Guard Strip." M. Gerard will, however, find it to be to the advantage of his Government to get the tramway companies to pay something towards removing all aërial conductors, which at present cross over trolley tramway routes. These should be replaced by either underground or by strongly suspended and insulated overhead cables, as explained in Part VII. of my paper. The former is, of course, the more perfect system, but at the same time the most expensive plan. Wherever the latter method is adopted, the aërial cables should cross tramway routes, as nearly as possible, at right angles. The spans should be as short as possible, and the aërial cables should be neatly and well hung from very strong steel wires. Wherever, either of these plans are adopted and thoroughly well carried out, I do not see any necessity for guard-wires of any kind, to trolley-wires. Should a fire occur in a building, so as to endanger the suspension of any aërial cable, then the current can be switched off from the affected section of the tramway system, until the danger is passed and the suspension again made reliable.

I am very glad to see that Mr. Blackburn's daily practical experience at Bradford, agrees with the descriptions and proposals made in my paper. I am particularly pleased to learn, that "Each car on the Bradford system has been fitted with an earthing switch, similar to that described in the paper." Further, that "No trouble has been found to arise in the working of this arrangement, and the delay to traffic is very much minimised by *every* man being in possession of a key for the street section pillar-boxes."

I am sorry, that the short time at the disposal of the meeting for the discussion of my paper, did not permit any representatives from the telephone, railway, and telegraph companies, expressing their views. But, I hope, that the combined new rules of the General Post Office, and the Board of Trade, may be delivered in their final authoritative form, before the issue of this discussion, to the members of the Institution. I understand that these rules have been submitted to all the most important and most interested authorities, and consequently they would form a very valuable addition to the paper and the discussion.

The PRESIDENT: I have now to ask you to return a hearty vote of thanks to Professor Jamieson for bringing this matter before us.

The resolution was carried by acclamation.

of "Trolley Wire Protection," devised by Prof. A. E. Salazer, of the Chili University. It is reported as having been adopted by the Chilian Electric Light and Tramway Company, Ltd., in Santiago de Chili. It consists of introducing an electro-magnet along with an additional resistance (which can be reduced to 250 ohms) directly into circuit with the *Earthing* wire, which is soldered to the guard-wires; at presumably, each half-mile section street pillar-box. When a sufficient current passes through one of these electro-magnets, its core attracts the armature catch of the section-feeder interrupter, and frees the section, wherein contact has been made (by a fallen telephone or telegraph-wire) between the trolley-wire and the guard-wire! This is, after all, but another "Quin device," and I should like to have an unbiassed and detailed report of the results, after at least one year of continuous use, in a damp, variable, dusty climate.

ELECTRICITY SUPPLY METERS OF THE ELECTROLYTIC TYPE.

By J. R. DICK, B.Sc., M.I.E.E.

In the evolution of the best supply meter, the type that survives will be the one that combines cheapness with the greatest permanent accuracy. In attempting to solve the problem, much attention has naturally been paid to electrolytic meters, on account of their inherent simplicity.

In all cases of electrolytic decomposition, the amount of electrolyte decomposed per second is directly proportional to the current. Meters constructed on this principle will, therefore, record (in the absence of polarisation or secondary actions) ampere-hours perfectly. Unlike motor meters, they require no compensation for frictional errors, and no special brakes to correspond with the law of the driving torque. In fact, the meter has a natural straight line law of registration.

In spite of these initial advantages, electrolytic meters generally have not obtained, from the station engineer's point of view, a lasting popularity. They have earned a bad reputation for various reasons, chiefly because they are "messy," and require attention for the renewal of electrodes or electrolyte, and because of the great drop of pressure with the unshunted varieties.

In Mr. Gibbings' paper in 1898, the unshunted types were discussed at considerable length; this paper will, therefore, be devoted to those which are shunted, with special consideration to those which depend on the measurement of the quantity of mercury deposited from a solution of a mercurous salt.

Before passing on to the latter, a reference to the water-decomposing meter as an instance of the extreme simplicity of the former type may prove of interest.

A multitude of patents have been taken out in this country and elsewhere on various forms based on this principle, but the simplest of the many alternatives was that originally suggested by S. D. Mott in the *Electrical World* of New York, of March 4th, 1893. In that article, Mr. Mott describes the meter as "measuring the amount of

water remaining after a certain amount of it has been decomposed," in other words, the residue of an electrolyte after subjection to electrolysis. Little attention appears to have been directed to this meter until the reading of Mr. Gibbings' paper, when it was revived in a practical form. The author believes this is the only unshunted electrolytic meter which has come into general use. However useful it may be for very small currents, it presents serious difficulties when large currents have to be dealt with. In such cases,

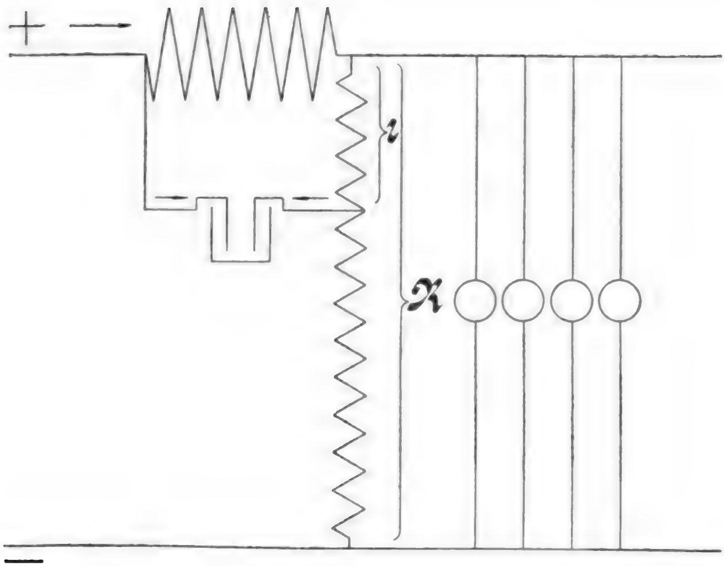


FIG. 1.

the drop in pressure must either be increased to an impracticable extent, or the meter must be shunted.

In employing a shunt to an electrolytic cell which has a back E.M.F., some compensating E.M.F. has to be inserted in the cell circuit in order to obtain a constant linear ratio between the main and the shunt currents. Several ways of effecting this compensation have been recently proposed by Mr. Arthur Wright. The most practicable appears to be that of placing a shunt across the supply mains (Fig. 1), and interpolating such a fraction of this in the cell circuit as will give a pressure exactly equal to the back E.M.F.

A direct proportionality will then exist between the main and shunt currents.

For example, in Fig. 1, if the back E.M.F. of the voltameter is 1·5 volts, the ratio of r to R must be the same as 1·5 to V—the supply pressure. The potential difference across r is then equivalent to a cell inserted in the shunt circuit, having a constant E.M.F. in the positive direction of the same amount as the counter E.M.F. of the voltameter. It is obvious that no current will pass through the voltameter when there is no current in the main circuit, as then the two E.M.F.'s in the shunt circuit exactly counterbalance each other.

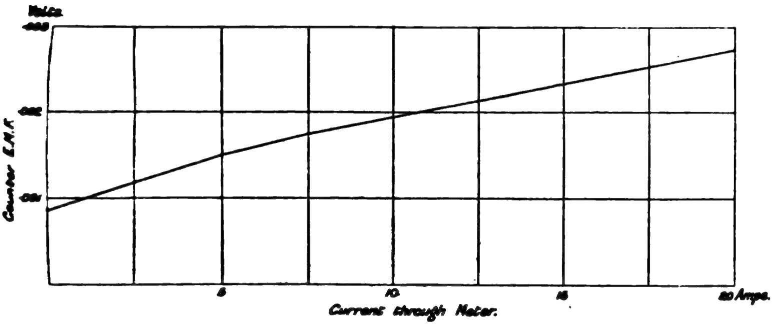


FIG. 2.

The shunt circuit constantly running with this arrangement detracts from the simplicity of the electrolytic method of registration, and increases the total loss of energy in the meter. To avoid this loss, and the complication of a compensated shunt circuit, it is infinitely preferable to utilise, if possible, an electrolytic cell where no back E.M.F. exists.

The Edison meter, in which were employed two amalgamated plates of pure zinc in zinc sulphate, aimed at this ideal. Theoretically there should have been no counter E.M.F., but in practice it was found that this was as high as ·0085 volt. The curve in Fig. 2 shows the values of the counter E.M.F. at various currents.

The error thus produced was negligible at currents of 10 to 20 amperes, but with currents of the order of one ampere it amounted to about 8·5 per cent. as the total drop in the meter was only 0·01 volt at this low load.

It would be too much to say that the use of Edison's chemical meter was discontinued because of its inaccuracy, as its average registration was fairly satisfactory. More probably it was on account of the troubles consequent on changing and weighing the plates, and conveying them to and from the consumer's premises. With the march of progress, engineers demanded a direct-reading instrument requiring no attention. Grassot's shunted electrolytic meter suffered from the same defect as Edison's, *i.e.*, under-registration at low loads. The correct registration of small currents has assumed a still greater importance since supply pressures of 230 and 250 volts came into general use, and a meter, to be successful, must be thoroughly suitable for these conditions.

The necessary characteristic of having a low back E.M.F. is common to all meters in which the amount of mercury liberated from a solution is used to measure the quantity of electricity passed through it. The highest accuracy can, therefore, be guaranteed even with very low currents. A variety of forms of such meters have been designed, but most of them suffer from various defects, and have not been generally employed.

In order to illustrate the difficulties that a meter of this type has to contend with, it will be best to examine some of the older designs.

The earliest of these is that of McKenna (1892). The reason of mercury being selected was primarily due to the facility with which the volume of the fluid metal deposited could be measured in a graduated vessel. As McKenna's specification says :—"The advantage (over Edison's) is that it enables the person using the meter to observe its registration at any time and without difficulty; whereas in meters of the ordinary form, the measurement is practically obtainable only by a skilled person who opens the instrument and weighs the deposit."

The illustration in Fig. 3 shows the apparatus, which consists of an anode of mercury contained in the pocket A, the cathode of carbon B, and the electrolyte. The latter is usually mercurous nitrate, as it is one of the most soluble salts of the metal. The monovalent salt has the incidental advantage that for the same current, twice as much metal is deposited as is liberated from the mercuric salt.

The electrolytic cell is connected across a low resistance shunt R inserted in one of the supply mains. A comparatively large resistance *r* is put in circuit with the cell itself,

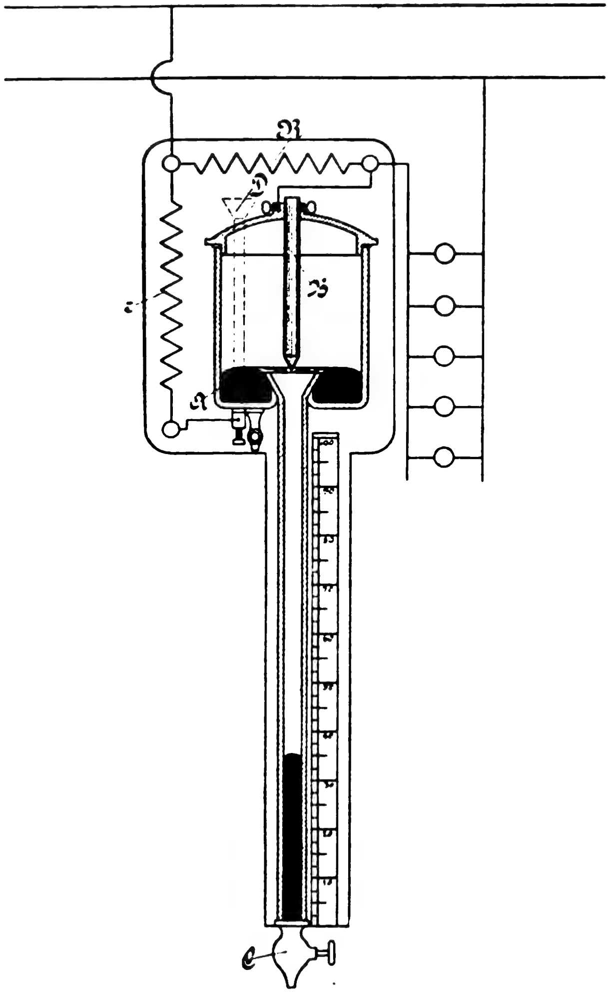


FIG. 3.

so that only a small fraction of the current passes through the electrolyte.

The action of the current is to deposit mercury on the carbon pencil, whence it drops into the graduated tube. By properly calibrating this tube, the meter may be made

to read directly the number of units consumed by the installation. The deposited mercury may be drawn off by the stop cock C, and returned to the anode by the funnel D.

Although this meter is excellent in principle, it could never be adopted in practice. The first defect to become visible in working would be a deposit of crystals at the anode surface. The electrolyte at this point becomes very rich in mercury, dissolved from the anode; ultimately it gets saturated, and deposits crystals, because there is no provision for agitating the solution and equalising the densities. There is a great increase of resistance due to this production of crystals, and the meter no longer gives accurate results. Further, as the mercury in the trough is dissolved and deposited in the tube, the surface falls below its original level, and the distance from the cathode increases, with a corresponding change in the internal resistance of the cell and an accentuation of the resistance error.

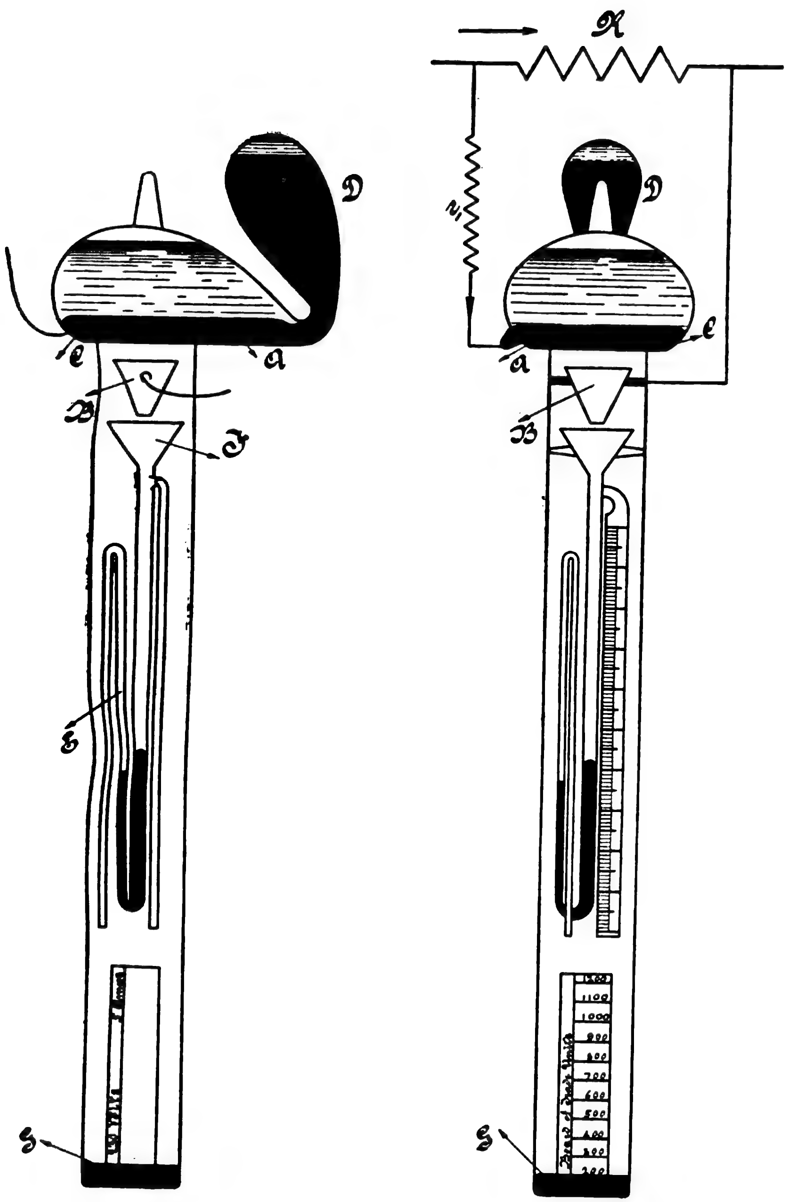
A third practical defect is the method of resetting the meter to zero, which is by drawing off the mercury and replacing it in the anode chamber. In this process dirt is certain to be introduced either into the metal or the solution, which will cause an irregular deposit when the meter next begins to register.

As is well known, too great care cannot be exercised in maintaining the chemical purity of mercury when used for electrolytic purposes.

Anders & Kottgen's meter (1892) is of the same class as McKenna's, and resembles it in almost every particular except that the cathode is an inverted cone of platinum instead of a carbon rod. The same observations are applicable to its action; and the same effects militate against its successful working.

Having exhibited these forms as examples of the hitherto vain attempts to produce a satisfactory shunted electrolytic meter, it remains now to show how the difficulties have been overcome.

The meter illustrated in Figs. 4, 5, 6 and 7, which has been devised by Mr. Arthur Wright, is the outcome of much thought and experiment in this province, and after being subjected to exhaustive tests, has given thoroughly satisfactory results.



FIGS. 4 AND 5.

The general principle of the meter is the same as already described, *i.e.*, the amount of mercury deposited from a solution of a mercurous salt is employed to measure the quantity of electricity: The various parts of the electrolytic cell are enclosed in a hermetically sealed glass tube, and advantage is of course taken of the fluidity of the metal to measure the volume deposited instead of the weight. The method of connecting up the meter is similar to McKenna's. The total resistance (including the cell) in the shunt circuit is about 40 ohms, and the maximum current in it is about 0·025 ampere for a meter of 5 amperes capacity. The resistance in the main circuit is of platinoid wire, and has a value of 0·2 ohm. What differentiates it at once from the other types is the change in the relative position of the anode A and cathode B. The former is now placed *above* instead of *below* the latter. The mercury of the anode is contained in a circular trough C, which is filled to such a height that the more concentrated solution formed by the electrolytic action falls off the convex surface of the mercury by gravity, and thus automatically mixes the liquid and tends to keep it of a uniform density. The aid of gravity in thus promoting diffusion would soon be ineffective if the mercury of the anode were to sink below the level of the lip of the trough. This is prevented, and constancy of level is obtained, by the employment of an anode "feeder" D, after the manner of the well-known "bird-fountain." When any portion of the mercury has been electrolysed from the anode and the level sinks to the smallest extent, it is quickly restored to its former height by a slight flow from the anode "feeder," while a corresponding amount of solution replaces the mercury thus withdrawn from the "feeder."

The cathode usually consists of a hollow cone of platinum foil or carbon, arranged concentric with the annular trough forming the anode.

The circulation of the electrolyte above described is reinforced by the cathode, as the lighter liquid produced at its surface tends to rise and replace the dense solution formed at the anode. The stream lines showing the relative circulation of the rich and impoverished solutions are illustrated in Fig. 8.

This interchange of solution goes on continuously, and

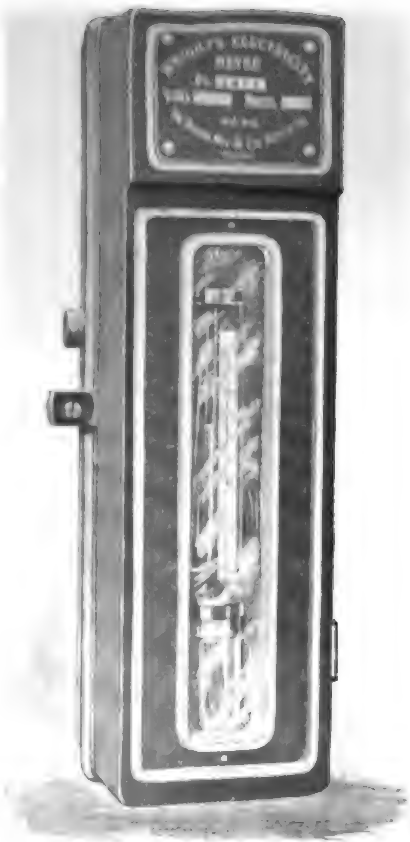


FIG. 6.

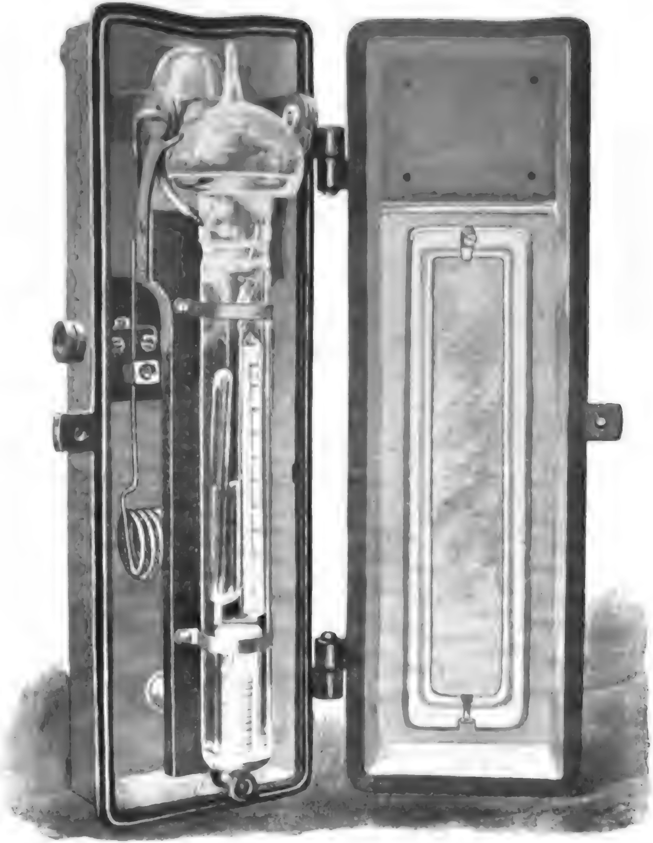


FIG. 7.

there is no need for agitation or stirring. The formation of crystals on the mercury anode, as explained above, was practically unavoidable in the earlier meters of this class unless extremely small currents were employed in the cell, and a long period of rest was occasionally given to permit the crystals to dissolve and the saturated solution to diffuse.

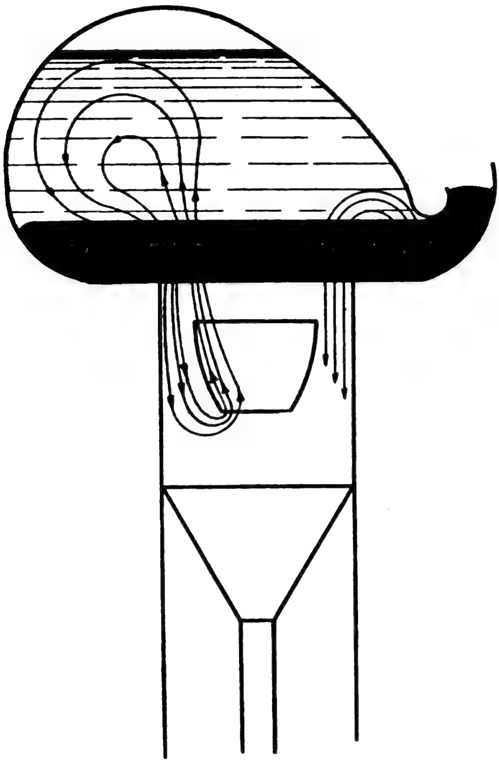


Fig. 8.

The large surface of the anode makes the internal resistance of the cell very small, and its symmetrical relation to the cathode makes the current density equal at each point, and therefore minimises any tendency to crystallise. The gravitational effect and the large extent of active anode surface permit of comparatively large currents in the cell before any signs of saturation of the solution become visible.

Consequently there is a large factor of safety between the working current density and that causing crystallisation. This factor of safety may be as high as four or five.

To secure accuracy with a shunted meter, it is a *sine quâ non* that the resistance of the cell itself should be constant, or nearly so. This is only possible where no change takes place in the areas of the electrode surfaces, or in the distance between the two electrodes, or in the density of the electrolyte.

In the present meter these first two essentials are fulfilled completely by the operation of the "anode feeder" in keeping the surface of the mercury in the trough always at the same height and of the same area, and the third is secured by the automatic circulatory process.

As is seen in Fig. 4, the meter is provided with two scales. The first of these is equal to 100 units and is fixed alongside one of the limbs of the syphon or U-tube E. The mercury that is deposited on the platinum cone drops in the form of minute globules into this tube, which opens out at its upper end into a glass funnel F, luted on to the main tube so that none of the mercury can escape falling into it and being measured.

When a quantity of mercury calibrated to be equal to 100 units has collected in the right-hand limb, it will stand at a level somewhat higher than the top bend of the syphon tube. This difference of head is sufficient to cause the syphon to come into action, and the whole of the mercury contained in the U-tube to be drawn over and fall into the lower receptacle G. This is graduated in such a manner that one division on its scale is equal to the complete volume of the U-tube. It therefore acts like the "second dial" of a clock-train counting mechanism; in other words, the range of the meter is very much increased, while the sensitiveness of the lower readings is not in the least impaired. A five-ampere meter furnished with these two "dials" will register conveniently up to 1,200 units. In fact the range of the meter is only limited by the weight of mercury it is advisable to have in the anode feeder.

Of course, a simpler type of meter having a range of about 250 units can be made in which the mercury deposited does not fall into a syphon tube, but into an ordinary tube reading direct in units.

When a full record has been obtained on the meter, it is necessary to reset it. This is done by tilting it up (like a demand indicator) on its hinged terminals, when all the mercury in the lower part of the tube will flow back into the anode chamber. A small hole is left in the glass funnel at the top of the syphon tube for the passage of the mercury. By this simple operation the meter is brought back exactly into its original condition. The cycle of operations can now recommence, and be repeated *ad infinitum.* It is interesting to note that this resetting is required only at long intervals. For a consumer with a five-ampere demand on 230 volts, 1,200 units would represent

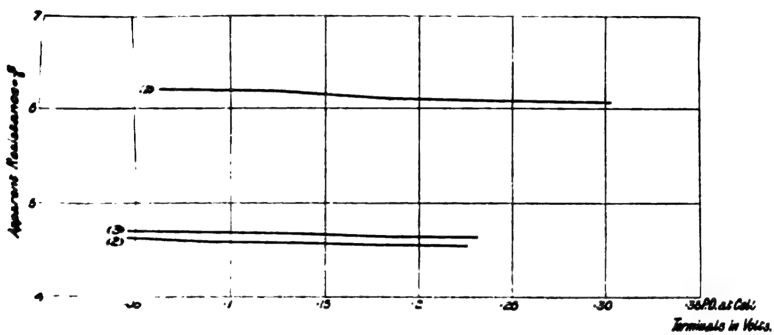


FIG. 9.

at least 1,000 hours all taken at the maximum load. This is equivalent to a year's consumption with 2·75 hours use per day of the maximum demand. In most cases, therefore, there would be no need to reset the meter oftener than once a year.

As previously mentioned, the glass tube is hermetically sealed. This is possible as the chemical action does not give rise to the production of gas, and consequently there is no internal pressure. As there is no opening to the air, there is no evaporation, no efflorescence, and no deterioration in the quality of the materials. The meter is not affected by atmospheric pressure, and only to a very small extent by external temperature. For this a simple means of compensation is available.

In very cold weather, there is the possibility of the solution in the meter freezing. This does not take place, however, even at a temperature of -4° C., and in the situations where meters are usually fixed, the temperature is not likely to fall below this figure.

The adjustment of the meter to read in B.O.T. units is an easy matter. The first essential is to obtain a clear reading. A quantity of mercury sufficient to occupy about one mm. length of the U-tube gives a quite sensitive enough indication for one unit. The syphon tube, although of very uniform bore, is always calibrated with a moving column of mercury like a thermometer tube, so that each of the divisions exactly equals one unit. The number of grammes of mercury per mm. or per unit can then be calculated from the volume of the tube.

The consideration that determines the amount of the resistance in the main circuit is the all-important one of the permissible drop in pressure. It ought to be as low as possible to prevent undue loss of energy, yet high enough to give a good reading for one unit. A limit of one-volt drop at full load has been chosen on 200 to 250 volt supply, this being a convenient figure and one that allows of a fairly large resistance being inserted in the shunt circuit. The current in the main which will convey a unit per hour is $\frac{1000}{V}$, where V is the declared pressure. The approximate value of the resistance in the shunt circuit is then found from the following formula derived from the equation $W = C\,T\,z$ grammes per mm. on scale $= \frac{1000}{V} \cdot \frac{R}{r} z$, where R is the main and r the shunt resistance, and z is the electrochemical equivalent in grammes of mercury in the mercurous state. The resistance of the cell is measured by a potentiometer method; knowing this, we can at once find the additional resistance r_1 to be placed in the shunt circuit to equal r.

A final correction in the relative values of the main and shunt resistances is provided for, after they have been checked by a "time" test of the meter by the following arrangement. The platinoid spiral of the former has two straight pieces near its ends which can be slid up or down in two terminals, and thus vary its amount. When exact adjustment has been made, the terminal screws can be sealed,

and there is no further possibility of altering the resistance or tampering with the meter's registration.

It is amply proved by the behaviour of the meter in practice that its design is successful in overcoming the inaccuracies to which the electrolytic type is liable. Various measurements have been made, however, with a view to checking the theoretical deductions described above, and also to ascertain the lowest current it is possible to register accurately.

The counter E.M.F. is the most important physical quantity in connection with a shunted electrolytic cell. This was determined very carefully at full load by direct reading, and the mean result of numerous tests on different meters gave a value of ·0001 volt.

The equation for E, the total E.M.F. between the electrodes of an electrolytic cell, has been shown to be—

$$E = Ri + \frac{\phi(i)}{i} + e,$$

where e is the counter E.M.F., i the current, R the resistance, and $\phi(i)$ is some function of the current.

Tests were taken to ascertain the importance of the last two factors on three meters, of which the first was freshly made up, the second had its cathode very thinly coated with mercury, and the third had the usual amount of mercury adhering after a long period of working. The curves in Fig. 9 are plotted to show the relation between E, the applied E.M.F., and $\frac{E}{i}$, the apparent resistance of the cell.

If the function $\frac{\phi(i)}{i} + e$ were equal to zero and R were constant, the curves would be straight lines parallel to the horizontal axis. The first diverges very little from parallelism, the second less, and the third (or working condition) is, within the limits of experimental error, almost parallel. The small counter E.M.F. in the first two instances may be accounted for by the fact that (according to Oberbeck) when a platinum plate is coated electrolytically with a metal, the electromotive force between it and a solution of that metal only gradually assumes the value observed for the massive metal as the thickness of the deposit grows.

It is extremely satisfactory to note from these tests that there is no counter E.M.F. due to the different degrees of concentration of the solution at the anode and cathode. In other words, the precautions taken to secure good diffusion have fulfilled their purpose. How great a value this counter E.M.F. of concentration may reach can readily be tested with a cell made up of half-normal and twentieth-normal solutions of mercurous nitrate and two mercury electrodes. A rough experiment gave an E.M.F. of 0·016 volt, which would be sufficient to cause very serious errors with small currents. It is this counter E.M.F. due to

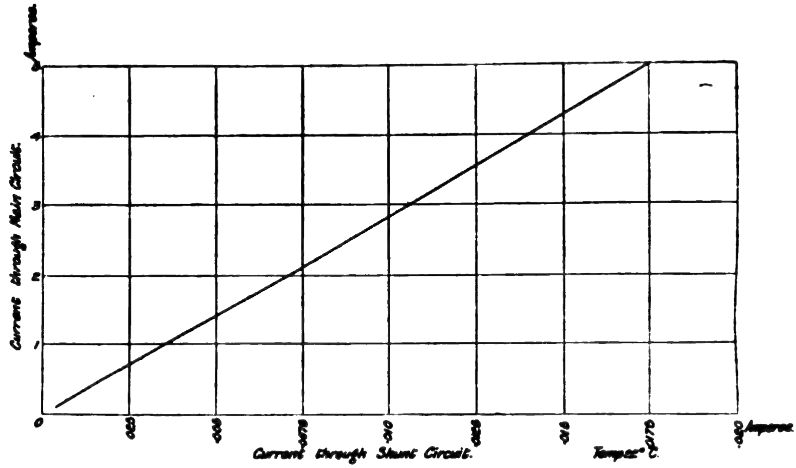


FIG. 10.

differences of concentration that manifested itself in the Edison, Grassot, and other shunted meters, and rendered them inaccurate even when the greatest care was taken to avoid it by working at very low current densities. It is an excellent thing to be able to show that the present meter has so many negative virtues. The vital question, however, is this: Does it in practice preserve a constant ratio between the current in the cell and the current to be measured? If so, the laws of electro-chemical action will take care of its accuracy.

Fig. 10 gives the results of experiments on this point. The curve is, within the limits of observation, a perfect straight line passing through the origin, and therefore

indicates exact proportionality of the main and shunt currents.

The only extraneous cause of variation the meter is

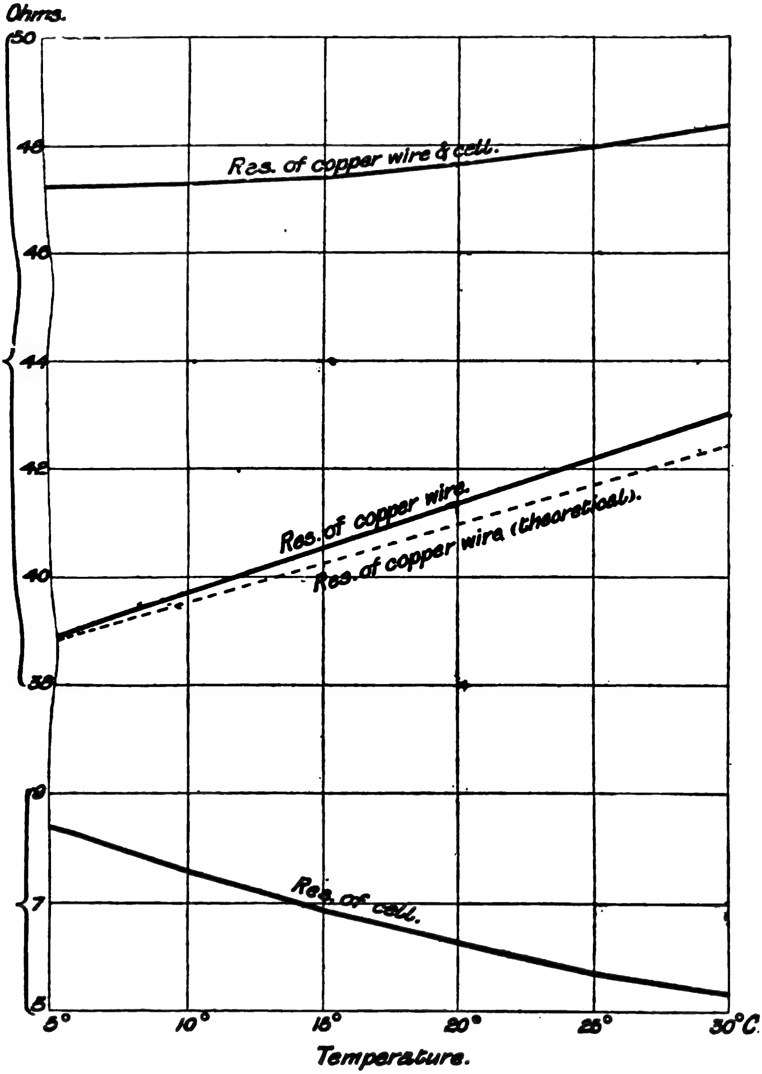


FIG. 11.

subject to is change of temperature. The electrolyte has a negative coefficient, while the copper wire of the resistance in series with it has a positive coefficient. The

combination of the two tendencies in suitable proportions will result in making the total resistance of the shunt circuit constant at all temperatures.

This method of compensation was first made use of by Edison in his Zinc Electrolytic Meter.

In Fig. 11, the tests taken of a 5-ampere meter are shown graphically. The variation of resistance in the cell itself is smaller than that of the copper-wire bobbin, when their resistances are seven and forty ohms respectively. Hence, if only copper is used, the diminution in resistance of the electrolyte would be over-compensated for ,and the meter would read low at high temperatures.

From the curves it is clear that in the present case a correction of 3 ohms is required between 5° C. and 30° C.; and therefore 29·5 ohms at 15° C. of copper wire will suffice, the remainder of the windings being of platinoid, or similar material. The curves of the properly compensated meter are exhibited in Fig. 11A.

The dotted curve shows how the resistance of the copper would have increased had it assumed exactly the external temperature. In point of fact, the increase was greater, as there was a considerable heating effect, due to the shunt current passing through it, and there being no opportunity for radiation.

After the lengthy explanation of the precautions taken to obviate the introduction of error from every possible source, it is not surprising that a very high degree of accuracy is obtained with this meter, not only with ordinary, but also with extremely small currents. All meters sent out can easily be adjusted, by means of varying slightly the main resistance, to register within one per cent. of accuracy.

Perhaps the most remarkable proof of this statement is the accompanying series of tests taken on three meters running continuously with 0·05 ampere. There was no standard meter to test them by at this current, and the units had to be calculated from the current (kept constant) and the time it was on. The duration of these tests had to be as long as four or five months, in order to get any range of reading.

It is noticeable that the error for the first ten units is considerable. This is due to some of the mercury de-

posited adhering to the cathode. Ultimately it falls off, and the quantity remaining is so small in proportion to the amount deposited that this error practically disappears. Even this temporary error of the retention of some of the

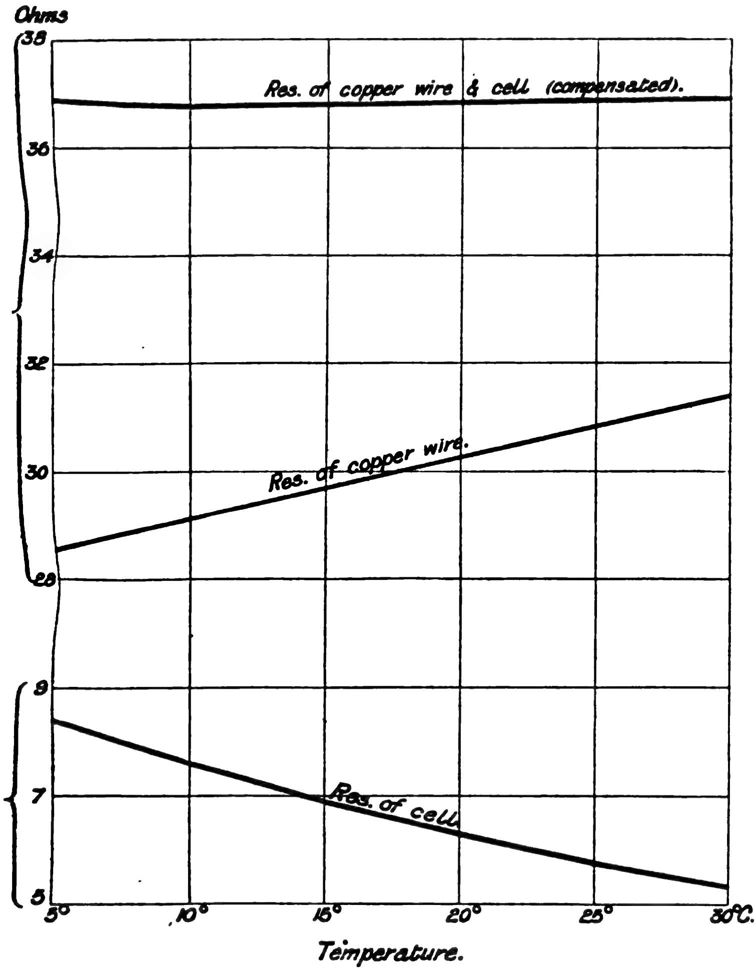


FIG. 11A.

mercury on the cathode is overcome by the employment of carbon instead of platinum foil.

Fig. 12 gives the graphic results of records with 0·05 ampere.

When such accuracy can be attained with currents lower

than any used for electric lighting, it does not *a fortiori* appear difficult to guarantee commercial accuracy within the limit of one per cent. stated above.

Fig. 13 represents the curves of three average meters.

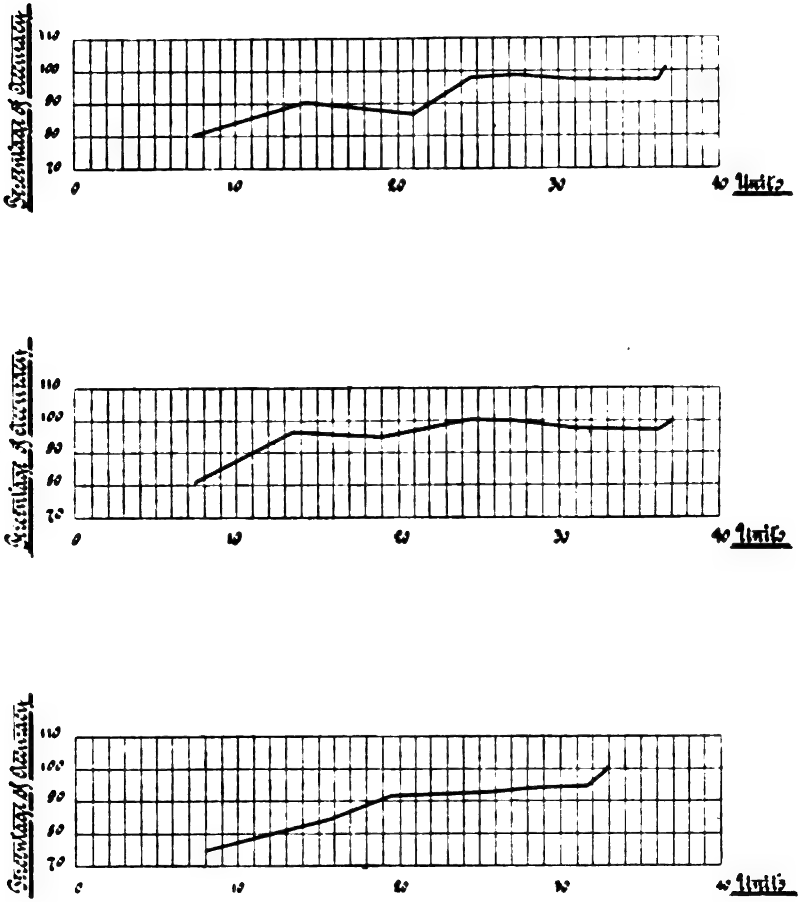


FIG. 12.

Of recent years it has become very generally recognised that some form of maximum demand indicator is a necessary adjunct to a meter, in order to determine a consumer's bill equitably. The additional drop of pressure at the lamps due to this second apparatus is sometimes com-

plained of, although even with a 5-ampere meter it does not exceed 0·6 or 0·7 volt. The Electrolytic Meter described can readily be combined with a thermal demand indicator in such a way that the heating resistance of the latter serves as a shunting resistance for the former, and no further loss of pressure is entailed than with a single instrument.

The total resistance causing the drop of 1 volt, on which

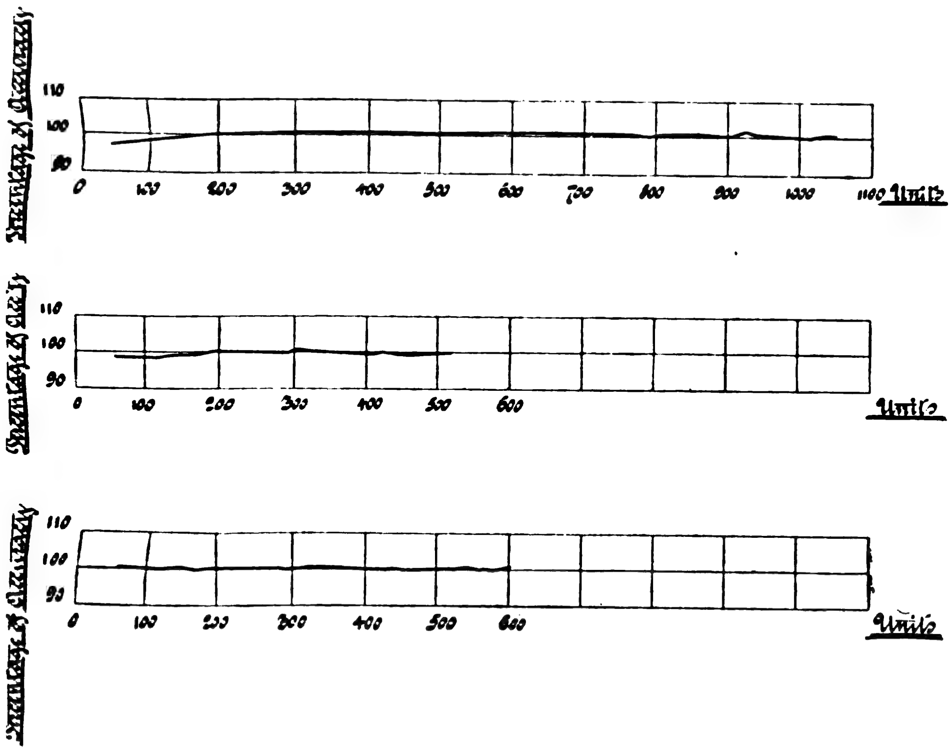


FIG. 13.

the meter proper is calibrated, is made up of the heating coil, together with an adjustable resistance of platinoid wire, in series, similar to that in the ordinary type described above.

Two views of the composite apparatus are given in Figs. 14 and 15.

The diminution of the pressure loss is not the only advantage possessed by this arrangement. It is exceedingly neat, and economises space in a consumer's installation.

In measuring the electricity consumed by an installation on the three-wire system, two meters have to be employed with most of the ampere-hour types. The present meter, however, can be easily adapted for such cases by means of a simple arrangement devised by the author, which answers perfectly for the usual method of wiring houses in England.

The installation is divided into two approximately equal sections, the neutral wire being split for this purpose. At the point of splitting A (Fig. 16), two low resistances, R_1 and R_2, are inserted of exactly equal value. The electrolytic cell, with its compensating resistance, is connected across the two further ends (C and D) of these resistances. When R_1 is equal to R_2, the current through the cell will be proportional always to the sum of the currents C_1 and C_2 in the two halves of the installation. For the total difference of potential between C and D is:—

$$C_1 R_1 + C_2 R_2,$$

or, when $R_1 = R_2 = R$,

$$R(C_1 + C_2).$$

Hence the current through the cell, and therefore its readings, will be proportional to the sum of the two currents exactly.

The only extra cost of a three-wire meter is that of an additional terminal and adjustable resistance.

Durability is an attribute of the greatest importance to any apparatus which has to be repaid by a sinking fund during a period of fifteen or twenty years. A short criticism of this meter from that point of view will, therefore, not be irrelevant.

Provided, as it is, with a strong cast-iron case, it can easily stand ordinary external wear and tear. Electrically, its main circuit is very permanent. The platinoid wire, which is not run at a high enough current density to get hot, will practically last for ever, and will not be damaged by a momentary short-circuit.

The liability to alteration in course of time in the electrolytic cell—the most important organ of the meter—is the only other point requiring consideration. As nothing is added to or taken from its components during working, and as there is no exposure to the air, the durability of the cell depends only on the chemical stability of the mercurous nitrate solution. Fortunately, this is used under precisely

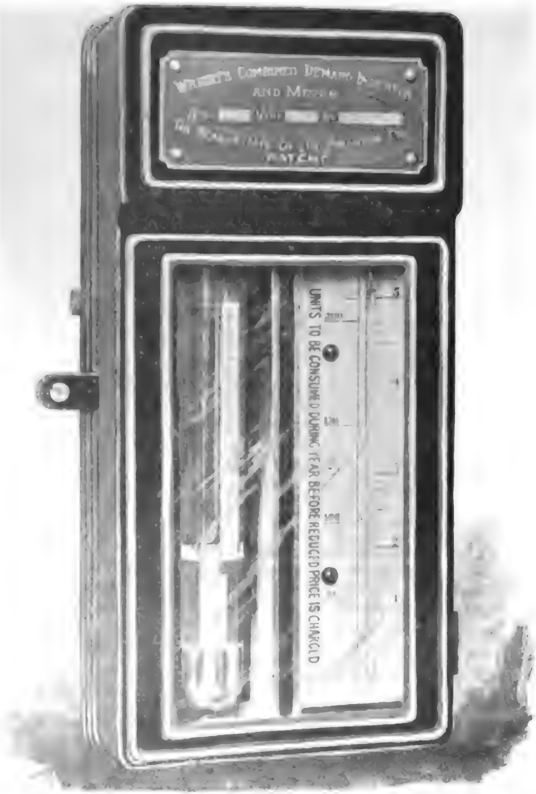

UNITS TO BE CONSUMED DURING YEAR BEFORE REDUCED PRICE IS CHARGED

FIG. 14.


UNITS TO BE CONSUMED DURING YEAR BEFORE REDUCED PRICE IS CHARGED
THIS SCALE INDICATES MAXIMUM CURRENT IN AMPERES

FIG. 15.

the condition requisite for its stability, *i.e.*, in presence of mercury. The chemical analyses made on meters that have been constantly working for eight months, and during that period have registered as many units as they would have done in five years in an ordinary installation, show identically the same proportion of mercurous nitrate in the solution as at first, and only a trace of mercuric nitrate—too small to be measured.

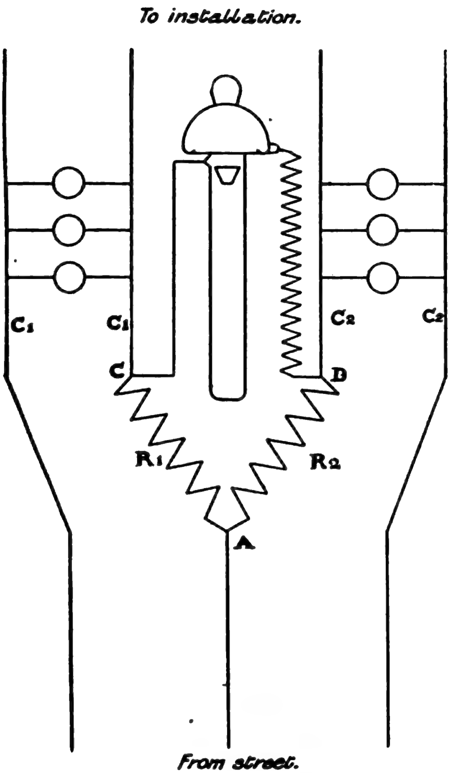


FIG. 16.

Great care is taken in the manufacture of the meter to use only chemically pure mercury and purified mercurous nitrate solution. The details of the necessary processes are, however, interesting only to the manufacturer. If the metal had to be removed and weighed, and fresh electrolyte added periodically, the introduction of impurities and consequent errors could hardly be avoided. In this permanence

of the constituent parts, therefore, the successful working of the meter is guaranteed, to all appearance, for an indefinite period without repairs or attention.

In concluding this description of the evolution of a good electrolytic meter, its chief features might be briefly recapitulated.

It is cheap in first cost; it has a very long range, and causes a very small drop in pressure.

It forms a most convenient combination with a demand indicator.

It will integrate any current, however small, with perfect accuracy. It requires absolutely no attention, and its cost of maintenance is nil.

The sense of security that such a meter should give to a central station engineer on the single point that every unit supplied to a customer is recorded, ought to, and is, removing the lingering objections which have hitherto attached to electrolytic meters as a class.

The PRESIDENT: I do not propose to call upon anybody to enter upon the discussion of this paper. Those gentlemen who wish to make any remarks will be kind enough to submit them in writing. The paper has been a very interesting paper, dealing with a most interesting subject. I have much pleasure in calling upon you to accord the author a hearty vote of thanks.

The vote of thanks was carried by acclamation.

The PRESIDENT: At the time we undertook to conduct the business of this section of the Congress it was thought that, in visiting Glasgow, it would be complimentary to our Local Section here to call for a paper upon those instruments which had been produced under Lord Kelvin's directions. While recognising that those instruments are, undoubtedly, well known to electrical engineers, it was felt that such a paper would be of interest to others than the members of the Institution who might be attending the Congress. Lord Kelvin was accordingly communicated with, and eventually Professor Maclean was good enough to draw up the paper which is before you. I may say that Professor Maclean has brought here several instruments which will be available for the inspection and examination of members of the Congress at the conclusion of the meeting,

KELVIN'S ELECTRIC MEASURING INSTRUMENTS.

By Professor MAGNUS MACLEAN, D.Sc., M.I.E.E.,

Chairman of the Glasgow Local Section, I.E.E.

The date of the beginning of exact electric measurements in electrical engineering may be roughly put about twenty years ago, and since that date Lord Kelvin has taken out 27 patents relating to improvements in instruments for generating, regulating, measuring, recording, and integrating electric currents. These patents contain (1) 185 pages of descriptive reading, and (2) 126 sheets having 297 figures or diagrams, as shown in a tabular statement in Appendix I. Appendix II. shows in a tabulated form the 11 patents relating to improvements in electric telegraphic apparatus. These patents contain (1) 211 pages of descriptive reading, and (2) 24 large sheets having 127 separate figures or diagrams.

Electric measuring instruments may be conveniently classified under four heads:—

A. Electrometers.
B. Electro-magnetic Instruments for measuring currents and differences of potentials.
C. Electro-dynamic Instruments for measuring currents and differences of potential, and electric activity.
D. Instruments arranged for recording and integrating electric currents.

A.—ELECTROMETERS.

Electrometers are divided into (1) symmetrical electrometers and (2) attracted disc electrometers. By means of these electrometers differences of potential from $\frac{1}{100}$ volt to 100,000 volts can be accurately measured. The symmetrical type of electrometers include (*a*) quadrant electrometers, (*b*) multicellular electrometers, and (*c*) vertical electrostatic voltmeters. The principle on which these instruments act is that of an air condenser, in which one metal part is movable about an axis, so as to increase or diminish the capacity. The magnitude of the force concerned in any case (except in the quadrant electrometer used heterostatically when the force is approximately in

simple proportion to the difference of potential between two pairs of fixed quadrants) is proportional to the square of the difference of potential between the fixed and movable parts. This force is balanced in the quadrant electrometers generally by a bifilar suspension, in the multicellular electrometers by the torsion of a suspending wire, and in the vertical electrostatic voltmeters by a weight of any convenient amount placed on the movable part. These instruments are so well known that no detailed description need be given of them (see Figs. 1 and 2). It may suffice to say that they have the great advantage of being available as accurate measurers of potential on direct and alternating systems. As they use no current, they require no temperature correction, and they are, therefore, free from the causes of error so prevalent in instruments of the electro-magnetic type, whose accuracy is impaired by variations of temperature, and which, when used on alternating systems, are affected by errors due to self-induction varying with the period of the alternation.

A. (2). The attracted disc electrometers include:—

(*a*) Absolute electrometers.
(*b*) Long range electrometers.
(*c*) Portable electrometers.
(*d*) Electrostatic balances.

Electrometers (*a*), (*b*), and (*c*) are described in detail in Kelvin's "Electrostatics and Magnetism." The fixed portion of the condenser in the electrostatic balance is a brass disc supported on three glass pillars, and the movable part is a round aluminium plate supported by two long links on two knife-edge stirrups on one end of a counterpoised indicator. The whole movable portion is supported by knife-edges on two brass pillars. The balancing force is the gravity of some definite weights supplied with the instrument, the weights being so graduated that differences of potential from 500 volts to 100,000 volts can be measured (see Fig. 3).

In connection with these electrometers, mention should be made of the Standard Air Leyden Condenser, as, in conjunction with a suitable electrometer, it affords a convenient means of quickly measuring small electrostatic capacities, such as those of short lengths of cables.

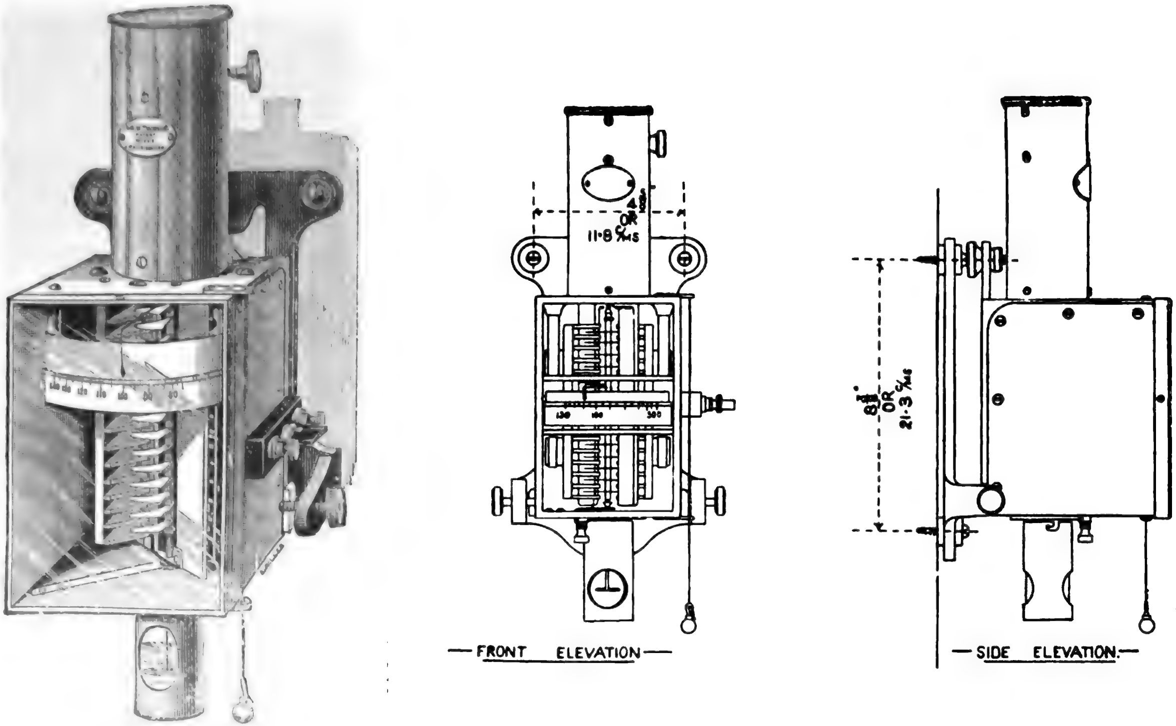


Fig. 1.—Multicellular Electrostatic Voltmeter.

FIG 2.—Vertical Electrostatic Voltmeter.

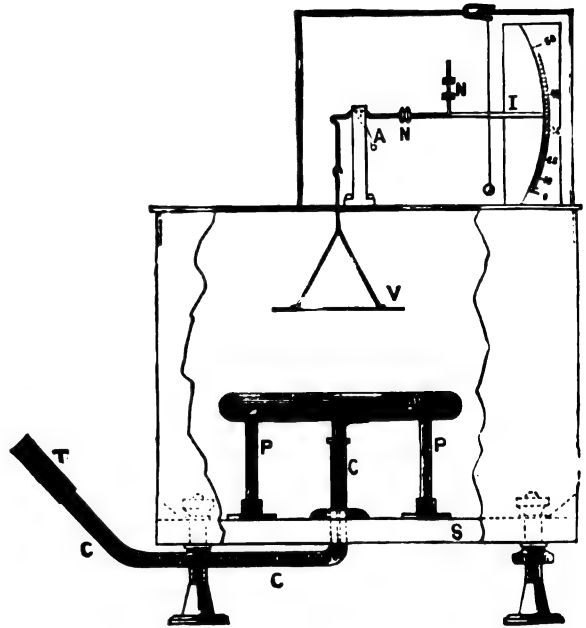


FIG. 3.—Electrostatic Volt-Balance.

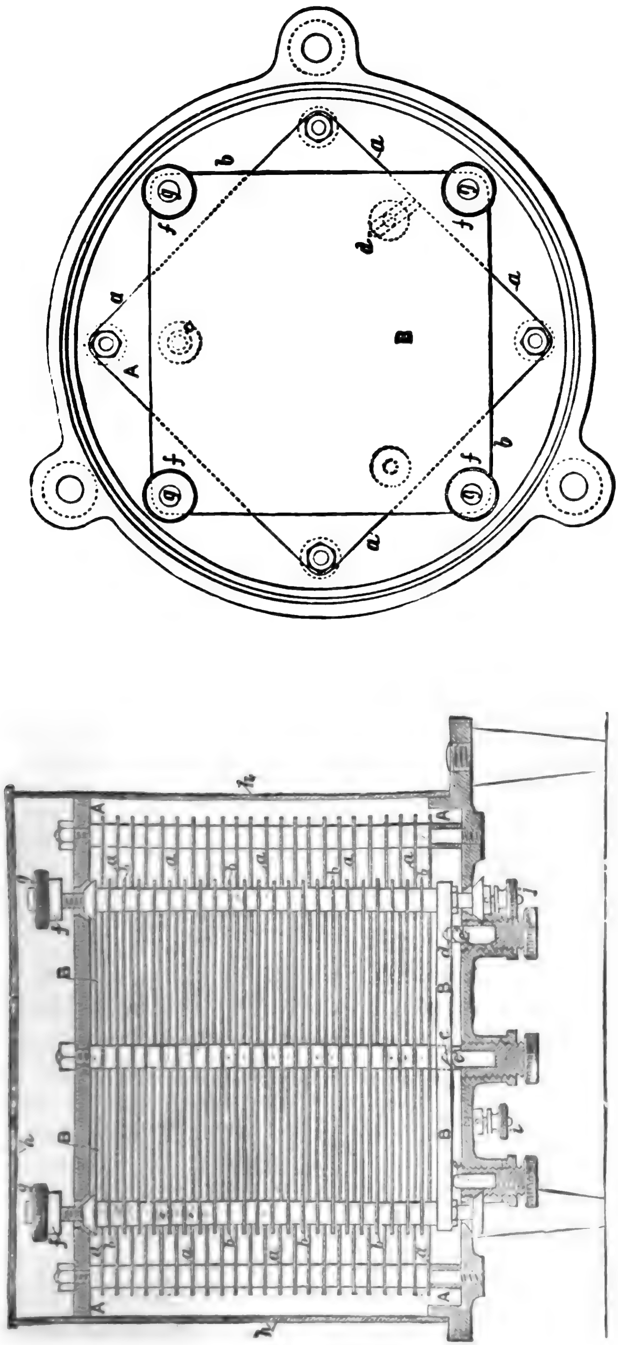


FIG. 4.—Standard Air Condenser.

The instrument is formed by two mutually insulated metallic pieces, A and B (see Fig. 4), constituting the two systems of an air condenser, or, as it may be called, an air Leyden. The systems are composed of parallel plates, each set bound together by four long metal bolts. The two extreme plates of set A are circles of much thicker metal than the rest, which are squares of thin sheet brass. The set B are all squares, the bottom one of which is of much thicker metal than the others, and the plates of this system are one less in number than the plates of system A. The four bolts binding together the plates of each system pass through well-fitted holes in the corners of the squares; and the distance from plate to plate of the same set is regulated

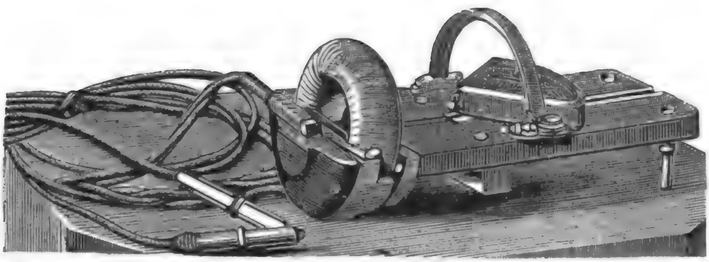


FIG. 5.—Potential Graded Galvanometer.

by annular distance pieces which are carefully made to fit the bolt, and are made exactly the same in all respects. Each system is bound firmly together by screwing home nuts on the ends of the bolts, and thus the parallelism and rigidity of the entire set is secured.

The two systems are made up together, so that every plate of B is between two plates of A; and every plate of A, except the two end ones, which only present one face to those of the opposite set, is between two plates of B. When the instrument is set up for use, the system B rests, by means of Lord Kelvin's well-known "hole, slot, and plane" arrangement engraved on the under side of its bottom plate, on three glass columns which are attached to three metal screws working through the sole-plate of system A. These screws can be raised or lowered at pleasure, and, by means of a gauge, the plates of system B can be adjusted to exactly midway between, and parallel to, the plates of system A.

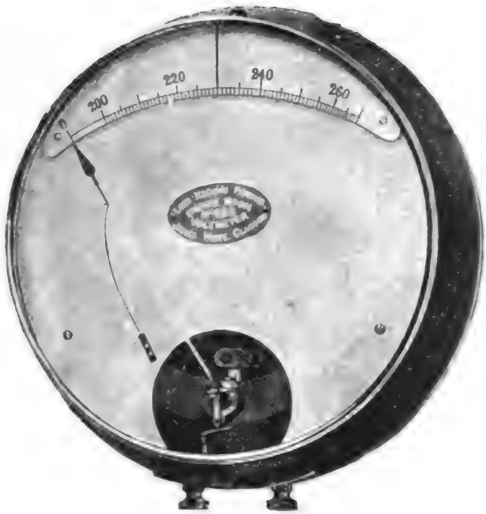


Fig. 6.– Round Pattern Suspended Coil Amperemeter and Voltmeter.

The complete Leyden stands upon three vulcanite feet attached to the lower side of the sole-plate of system A.

In order that the instrument may not be injured in carriage, an arrangement, described as follows, is provided by which system B can be lifted from off the three glass columns and firmly clamped to the top and bottom plates of system A: The bolts fixing the corners of the plates of system B are made long enough to pass through wide conical holes cut in the top and bottom plates of system A, and nuts at the top end of the bolts are also conical in form, while conical nuts are also fixed to their lower ends

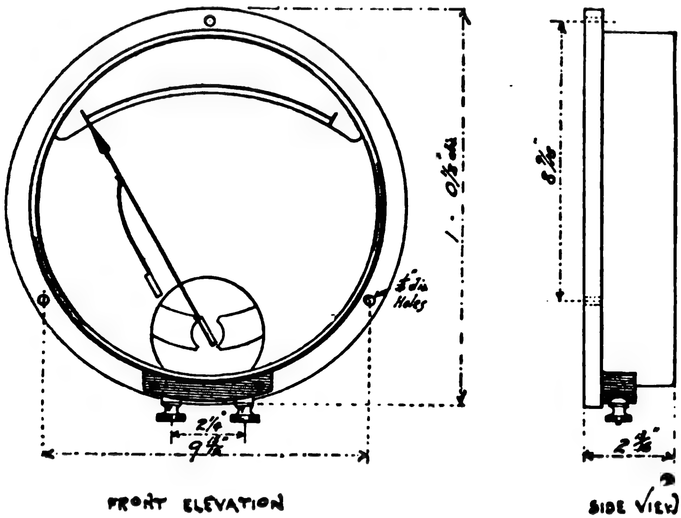


FIG. 7.—Round Pattern Suspended Coil Amperemeter and Voltmeter.

below the base-plate of system A. Thumbscrew nuts, *f*, are placed upon the upper ends of the bolts after they pass through the holes in the top plate of system A. When the instrument is set up ready for use, these thumbscrews are turned up against fixed stops, *g*, so as to be well clear of the top plate of system A; but when the instrument is packed for carriage, they are screwed down against the plate until the conical nuts mentioned above are drawn up into the conical holes in the top and bottom plates of system A; system B is thus raised off the glass pillars, and the two systems securely locked together so as to prevent damage to the instrument. A dust-tight cylindrical metal case, *h*,

which can be easily taken off for inspection, covers the two systems and fits on to a flange on system A. The whole instrument rests on three vulcanite legs attached to the base-plate on system A, and two terminals are provided—one, *i*, on the base of system A, and the other, *j*, on the end of one of the corner bolts of system B.

B.—ELECTRO-MAGNETIC INSTRUMENTS.

B. (1). Among the earliest of the electro-magnetic instru-

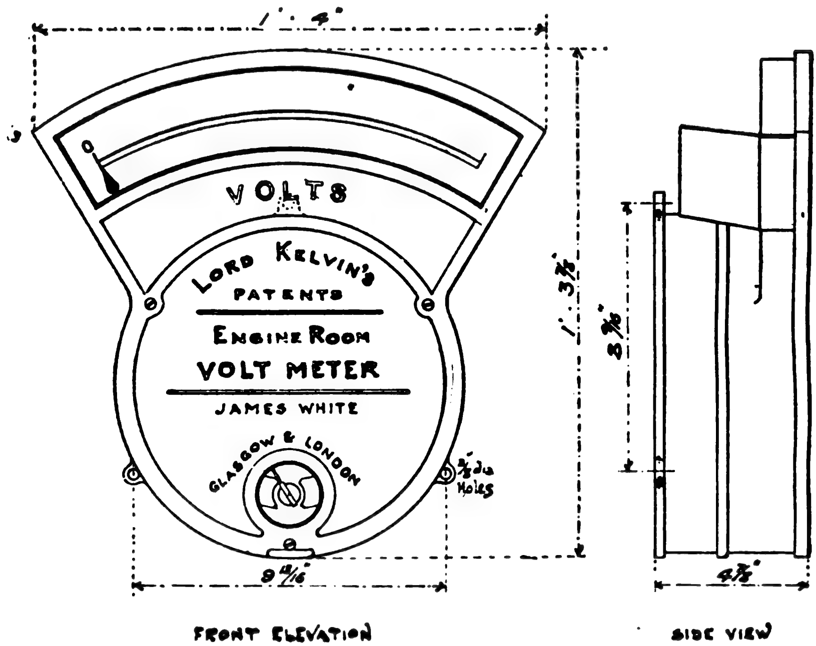


FIG. 8.—Illuminated Dial, Thistle Pattern, Suspended Coil Amperemeter and Voltmeter.

ments (leaving out of account the reflecting, differential, and ballistic galvanometers of more than forty years ago), and certainly among the most convenient for giving a very wide range of current measurement, were the graded galvanometers. The current galvanometer instrument consists of a coil made up of a few turns of thick copper strip having a resistance of about one thousandth of an ohm. This coil is fixed to one end of a platform, on which a magneto-

meter rests. The magnetometer is supported on three feet and a spring; two of these feet slide in a "V" groove, cut in a slip of hardwood let into the top of a platform, and this allows the magnetometer to be moved nearer to or further from the coil, but prevents it being so turned round as to change the zero reading of the instrument. The sensibility of the instrument is changed by changing the position of the magnetometer on the platform. By means of this instrument currents from 4 milliamperes to 200 amperes can be accurately measured. The potential graded galvanometer is similar in form with the exception that the coil consists of insulated wire the resistance of which is generally over 5,000 ohms. Differences of potential from a small fraction of a volt to 200 volts can be readily measured by means of it. Both these galvanometers are of the movable needle type (see Fig. 5).

B. (2). Of recent years Lord Kelvin has reverted to his siphon recorder type of instrument in which there is a movable coil in a fixed magnetic field. The first instrument of all the suspended coil pattern was Weber's electro-dynamometer, in which a fixed coil acted on a movable coil capable of rotational displacement round an axis. The first suspended coil instrument with field due to a steel magnet was the invention of the Rev. H. Highton. The coil was supported on pivots between the poles of a steel magnet. It was used by the British and Irish Telegraph Company as a receiving instrument about 1856 and 1858. Lord Kelvin greatly improved this form of instrument by introducing a fixed soft iron core in the siphon recorder of 1867. This soft iron core has made the present form of instruments practically valuable. And now there are six types of these movable coil instruments manufactured, each of which can be used for measuring currents or differences of potentials. The permanent magnets are circular compound horse-shoe magnets specially treated to ensure permanency. With good quality of steel, a proper preliminary ageing of the magnets (by heating them several times in boiling water and cooling them again, and subjecting them to somewhat varied usage) brings them to a condition in which the magnetism is found to remain exceedingly nearly constant month after month and year after year. The coil or movable system is supported on ligaments, or flat spiral

springs, which also act as the conductors of the current, and thus friction due to pivots is entirely avoided. In the voltmeter type any degree of sensibility can be attained with perfectly dead beat action, and ranges up to 1,000 volts. There are six patterns. In patterns 1 to 5 the movable coil is suspended by a flat spiral spring, as seen in Figs. 6, 7, 8, and 9. In the reflecting mirror pattern the movable coil is supported by a flat metallic strip fixed at the top and the bottom (see Fig. 10).

1. Edgewise.
2. Round. Figs. 6 and 7.
3. Illuminated Dial Thistle. Fig. 8.
4. Portable in aluminium case.
5. Portable paralleling. Fig. 9.
6. Reflecting mirror. Fig. 10.

All these instruments can be used as shunted ammeters to measure currents with fair accuracy. Shunts can be provided to register currents up to 1,000 amperes. I have found pattern 4 specially handy for laboratory work. With the instrument direct and three specially prepared shunts I can measure continuously currents from $\frac{1}{20}$th milliampere to 20 amperes. The scale has 50 divisions, and the constants are as follows:—

	Constant.	Range of Readings.
Instrument unshunted	50 mikroamperes per division	$\frac{1}{20}$ milliampere to $2\frac{1}{2}$ milliamps.
1st shunt	1 milliampere per division	1 milliampere to 50 milliamps.
2nd shunt	20 milliamperes per division	20 milliamperes to 1 ampere.
3rd shunt	0·4 ampere per division	0·4 ampere to 20 amperes.

The suspended coil portable pattern can also be used as a millivolt or milliampere meter. Hence it is suitable for making conductivity tests of tram rails, or detecting faulty bonds. For this purpose a graduated bar with two steel contacts, as shown in Figs. 11 and 12, is provided. The

FIG. 9. Portable Paralleling Voltmeter.

FIG. 10.--Suspended Coil Reflecting Galvanometer.

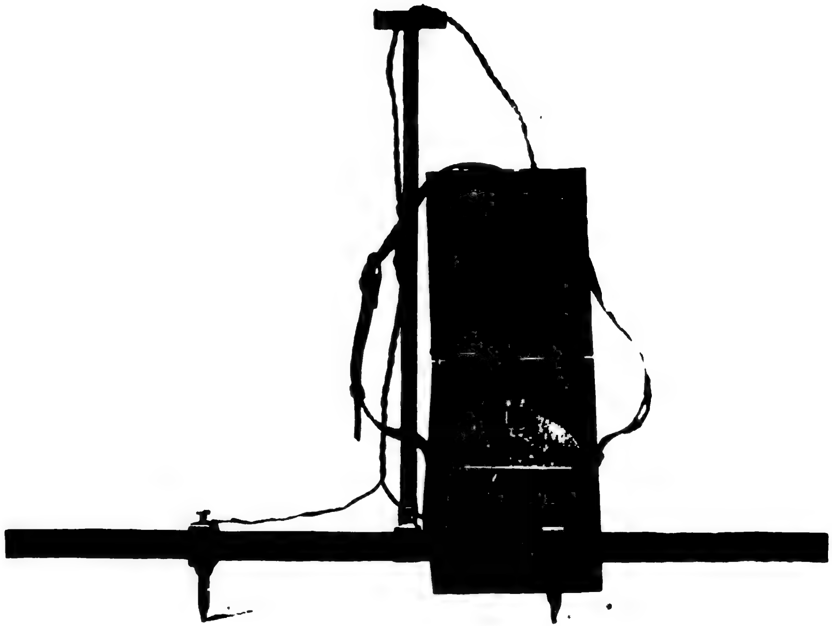
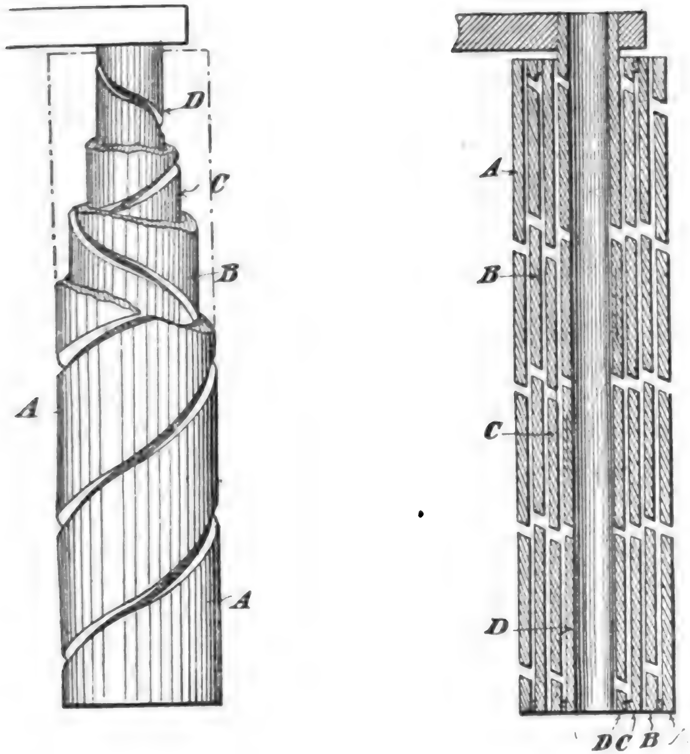


FIG. 11.—Rail Tester.

FIG. 12.—Rail Tester in Use.

suspended coil voltmeter is carried in a light teak case (Fig. 12). As the two steel contacts can be altered in position along the graduated bar, various degrees of sensibility can be obtained.

The suspended coil portable paralleling voltmeter (Fig. 9), used with suitable sockets in the switchboard, forms a very



Figs. 13 and 14.—Coil of Ampere Gauges.

handy and expedient method of paralleling. It is arranged with a central zero; the connections are such that the currents from the dynamo which is running and the one it is desired to put in parallel with it oppose each other, and so when the potential of the two dynamos is the same the instrument indicates at zero.

B. (3). The ampere gauges, which were intended for use on switchboards, have had two very important improvements introduced of late years. The first improvement

relates to the coil, the object of which is to obtain a coil which will give a more uniform field than is attained by ordinary methods. The coil consists of two copper tubes (two or more may be used), one smaller in diameter than the other. A spiral cut is made in each from near the top to near the bottom (see Figs. 13 and 14). The spiral cuts in the two tubes are right-handed in one and left-handed in the other. The smaller tube is placed inside the other, with the space between them occupied by air or solid insulating

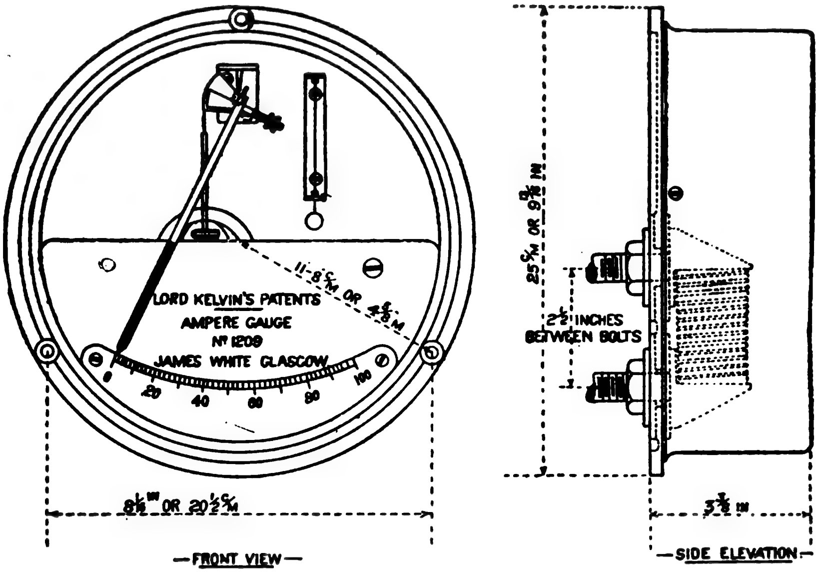


FIG. 15.—Sector Pattern Ampere Gauge.

matter. The two tubes are connected together at the top. The current goes up the copper spiral of one tube and down the spiral of the other tube. Thus a very uniform field through almost the whole length of the cylindric space within the coil is obtained. The second improvement relates to the method of suspending the soft iron plunger which is now suspended from a sector (see Figs. 15 and 22 to 24). On account of the sector maintaining the movement of the plunger up and down in the same vertical straight line, it keeps the moment of the force exerted on the movable system always exactly proportional to the force

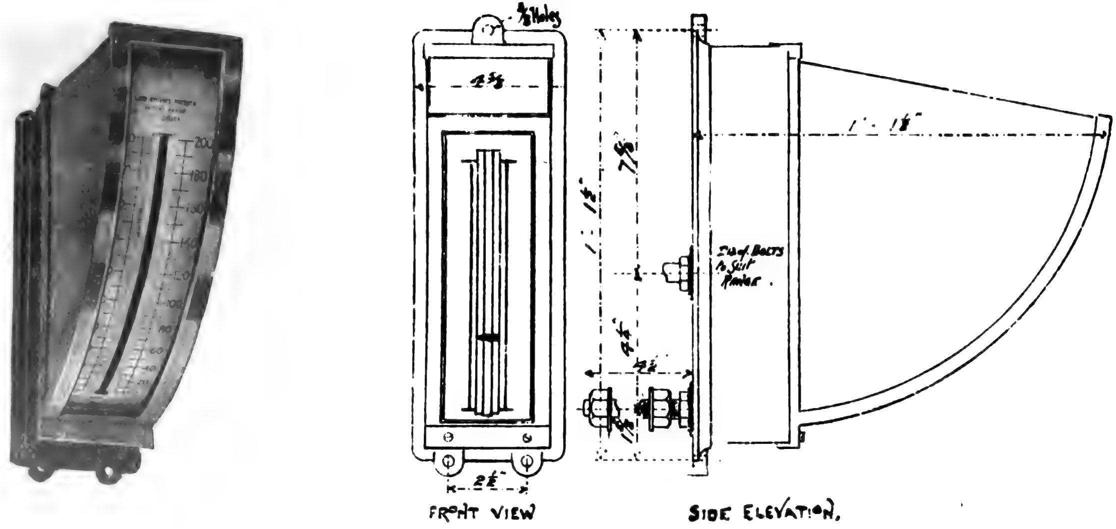


FIG. 16.—Edgewise Pattern Ampere Gauge.

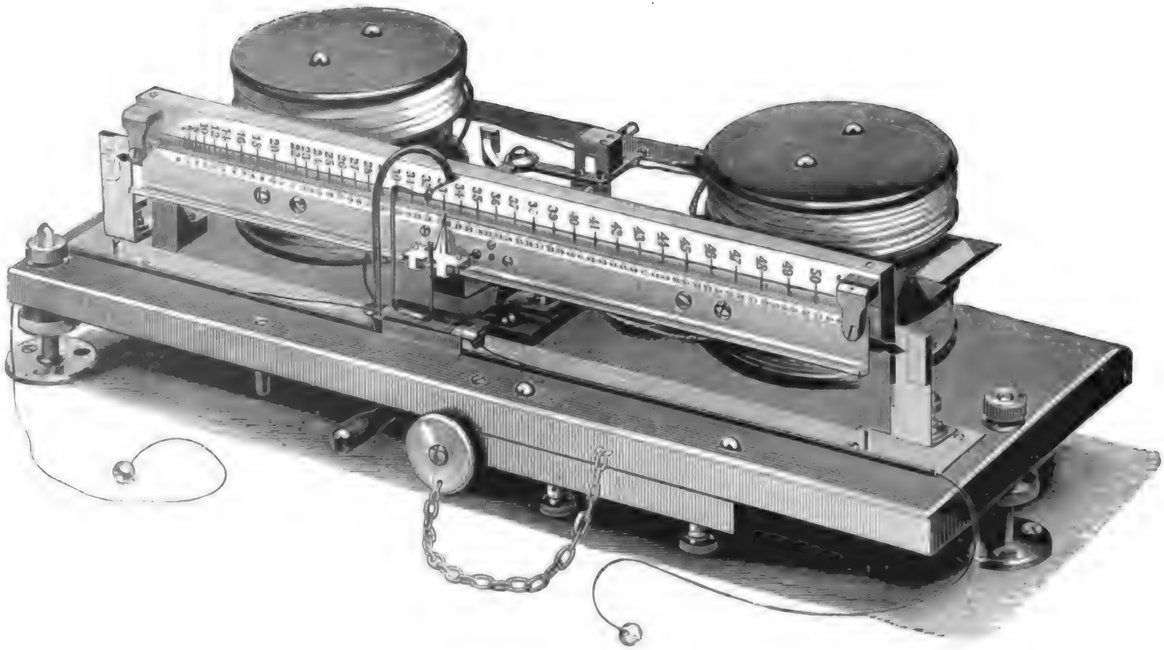


FIG. 17.—Deci-Ampere Balance.

exerted by the current on the plunger in any position. Thus there is obtained a much more evenly divided scale than in the older type. In the old form of the instruments the coil required to have a slotted hole in order to allow of the horizontal movement of the plunger, which was caused by the circular motion of the point of suspension of the movable system. With this new form of coil and by the use of the sector, the force of the current is greatly concentrated and much more uniform, and the horizontal movement of the plunger is completely done away with.

On account of the intense field of these solenoidal coils, and the fact that the movable magnetic bar is always vertical, these instruments are not affected by switchboard currents. The ranges of the different types are such that currents from $\frac{1}{10}$ to 4,000 amperes or more can be accurately measured by them. The instruments measure the current independently of the direction in which it is flowing; but where it is desired to know the direction, as in accumulator or middle-wire circuits, a current direction indicator is fitted to the lower end of the scale. An edgewise pattern with similar ranges of currents is made (Fig. 16).

For the ranges above 2,000 amperes the solenoid is replaced by a simple straight, horizontal conductor of sheet copper two or three millimetres thick and four or five centimetres broad in a vertical plane. The soft iron plunger is made of hair-pin shape, the conductor passing between the two ends of this plunger. The effect of the current passing through the conductor is to magnetise the plunger, one end having north and the other south polarity. As the north pole is pulled downwards on one side and the south pole on the other, the hair-pin plunger gives double the force which would be obtained by a single plunger on one side of the conductor. Besides this there is the advantage of the hair-pin shape which allows the poles to be in close proximity to each other, very advantageously in respect to magnetisation of the horse-shoe.

C.—Electro-dynamic Instruments.

The electrodynamic instruments are founded on the mutual forces, discovered by Ampere, between movable and

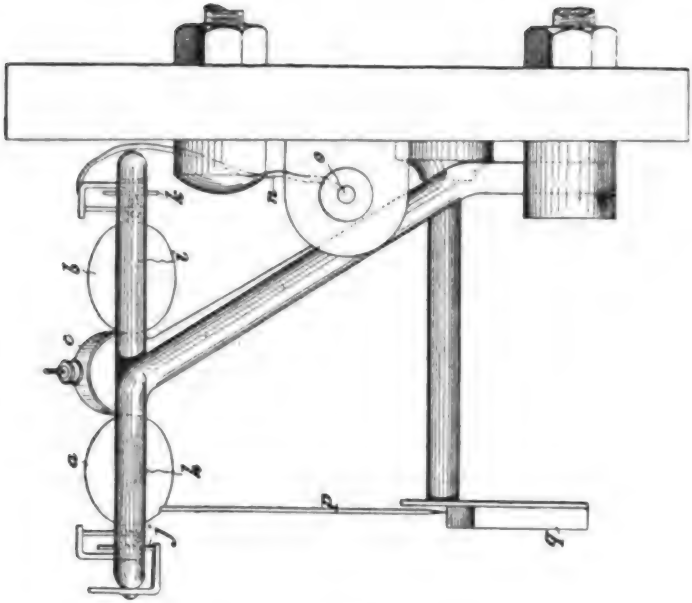


FIG. 19.—Engine-room Wattmeter : Side Elevation.

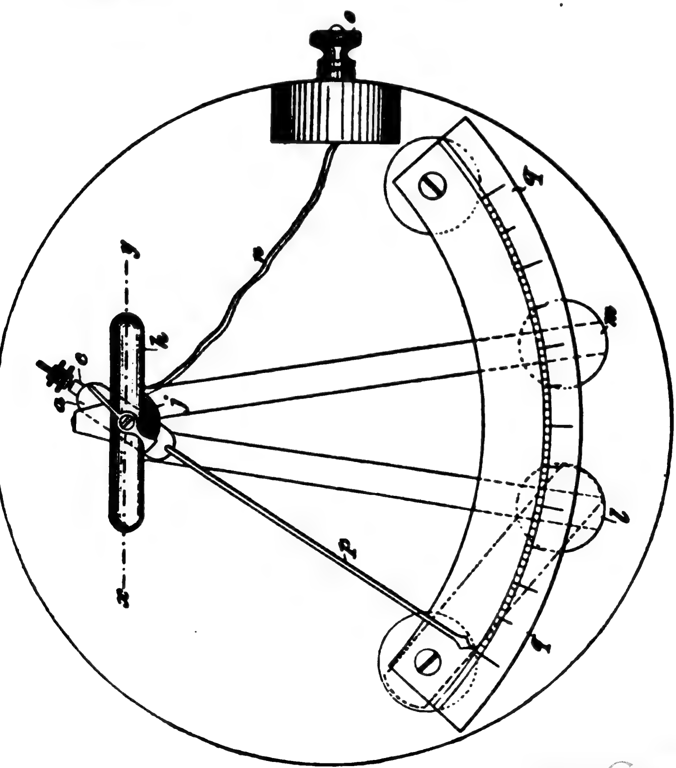


FIG. 18.—Engine-room Wattmeter : Front Elevation.

fixed portions of an electric circuit. The current instruments measure from 1 centi-ampere to 2,500 amperes, and the watt instruments measure up to 50 kilowatts and to 10,000 amperes. The balancing force is a weight which slides on an approximately horizontal graduated arm attached to the movable coils of the electric balances. All the ampere balances are suited for the measurement of direct or alternating current. The deci-ampere balance (Fig. 17) may be taken as a type of these well-known standard instruments.

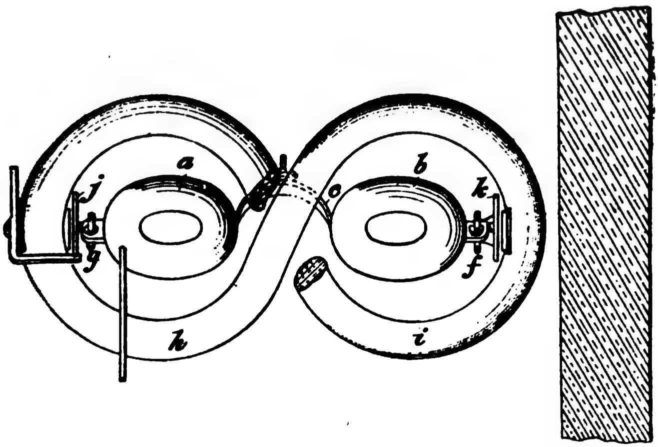


FIG. 20.—Engine-room Wattmeter: Horizontal Section of Movable System.

The new engine-room wattmeter has a main circuit formed of a double rectangle of copper rod having sufficient area to carry 200 amperes, and a shunt circuit with two fine wire coils astatically arranged. The main coil is mounted on a slate back, so that the rectangles are horizontal. The shunt coils are mounted on a light but strong aluminium frame. One end of this frame has a circular knife-edge hole fixed to it, and the other end has a straight knife-edge. These two knife-edges rest on two phosphor-bronze hooks attached by insulating supports to the outside ends of the double rectangle. By this method of suspension excellent freedom from friction is obtained, while the movable system is kept in a definite position without end guides. Each

fine-wire coil has about a thousand turns of insulated wire, and its resistance is about 100 ohms. The current is conducted in and out from the movable system by two flat palladium springs, which also supply the balancing force for governing the sensibility of the instrument. Not more than one-twentieth of an ampere is allowed to pass through the fine-wire circuit, and, in order to regulate this, a large non-inductive resistance is rolled on the case of the instrument, which offers a large cooling surface. The scale has nearly uniform divisions, and is graduated to read directly in watts or kilowatts as required. Fig. 18 is a front elevation; Fig. 19 is a side elevation; Fig. 20 is a horizontal section, on the line x y of Fig. 18; and Fig. 21 is

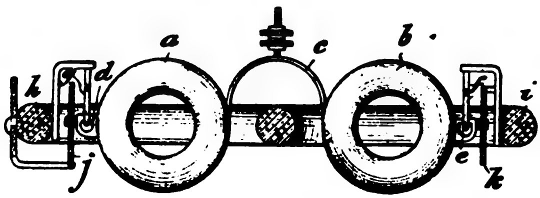


FIG. 21.—Engine-room Wattmeter: Vertical Section of Movable System.

a vertical section showing the method of supporting the movable system.

In the three-phase wattmeters there are two sets of main coils and two sets of shunt coils. The shunt coils form the movable system. They are coupled together, and the pointer, which moves over a scale of watts or kilowatts, is rigidly attached to them. Each of the movable coils has 1,510 turns, made up of 51 metres of No. 40 copper wire and 60 metres of No. 50 copper wire. The resistance of each coil is 317 ohms. The number of turns and size of conductor in each of the two fixed coils vary according to the range of the instrument. For a one-ampere instrument each coil consists of 300 turns of No. 22 copper, and for a 500-ampere instrument 1 turn of $\frac{3}{8}$-inch diameter copper rod.

D.—Recording Instruments.

The recording instruments are Amperemeters, Voltmeters, and Wattmeters. The recording amperemeters and voltmeters are of the ampere gauge sector pattern. A drum, round which a record paper is fixed by a metal

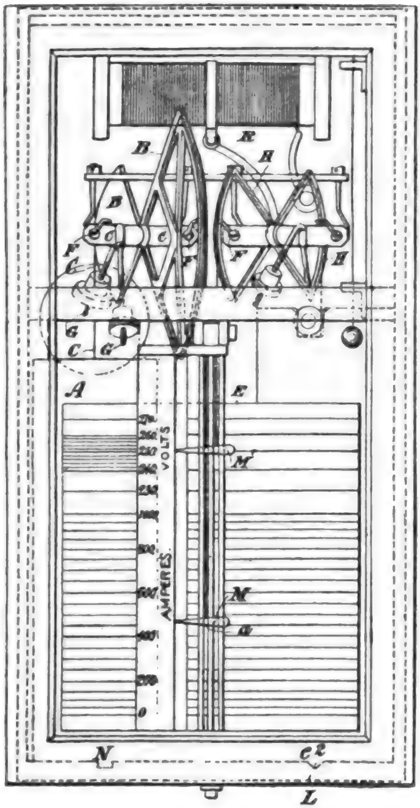


Fig. 22.—Feeder Log: Front View.

band, is revolved by means of a clock inside it. A pen which is attached to the lower end of the plunger rests against the paper on the drum with a small component of its own weight. This component is sufficient to give a good marking without introducing too much frictional error. A combination of a recording voltmeter and a recording amperemeter, called a Patent Feeder Log, has been

found very valuable in electric supply stations. Fig. 22 is a front view and Fig. 23 is a side view. There is a double sector for both the current coil and the potential coil. From one side of the double sector is suspended the soft iron plunger which moves up and down in the axis of the solenoid, and from the other end of the sector is suspended

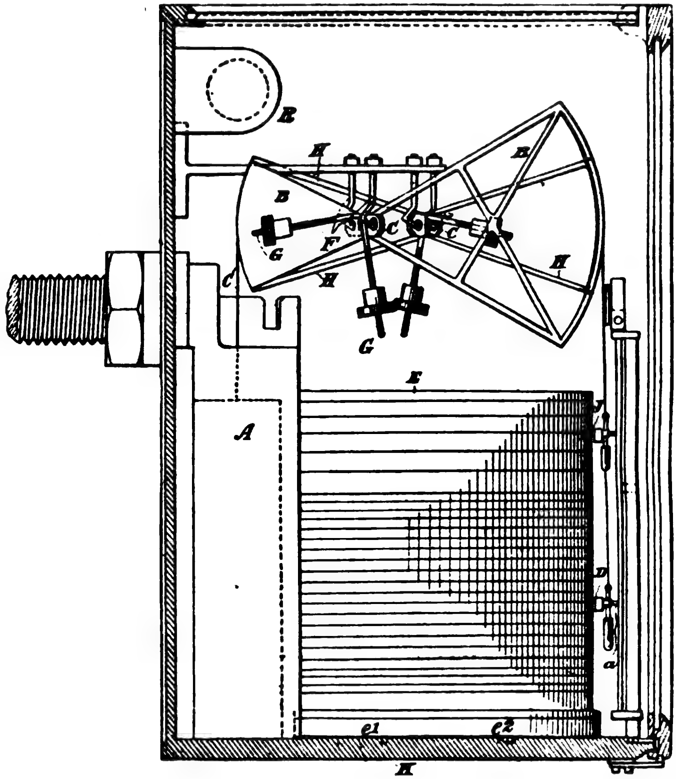
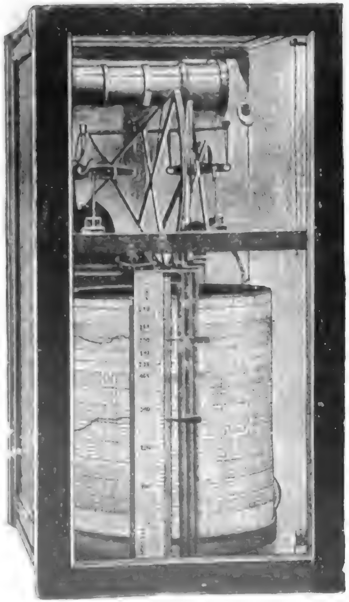


FIG. 23.—Feeder Log: Side View.

the pen which bears against the record paper. One pen marks the value of the current passing, and the other pen is arranged above it to mark on the same time line the magnitude of the difference of the potential at the station, or at the feeding point. Fig. 24 shows the paper drum drawn out and turned downwards into a convenient position for changing the recording paper.

The Astatic Recording Voltmeter for alternating currents



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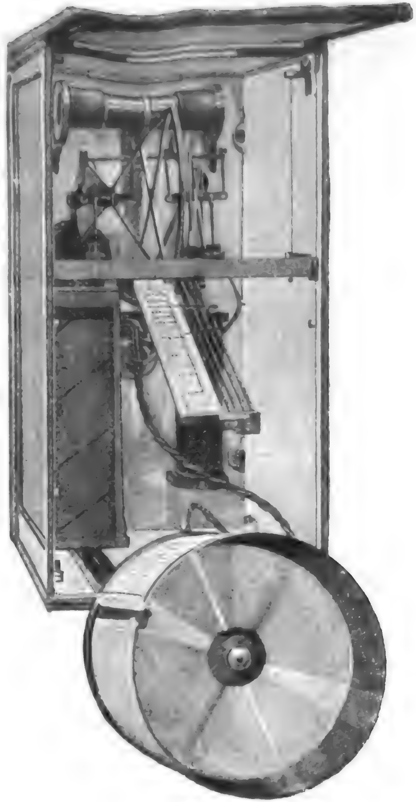

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FIG. 24.—Feeder Log.

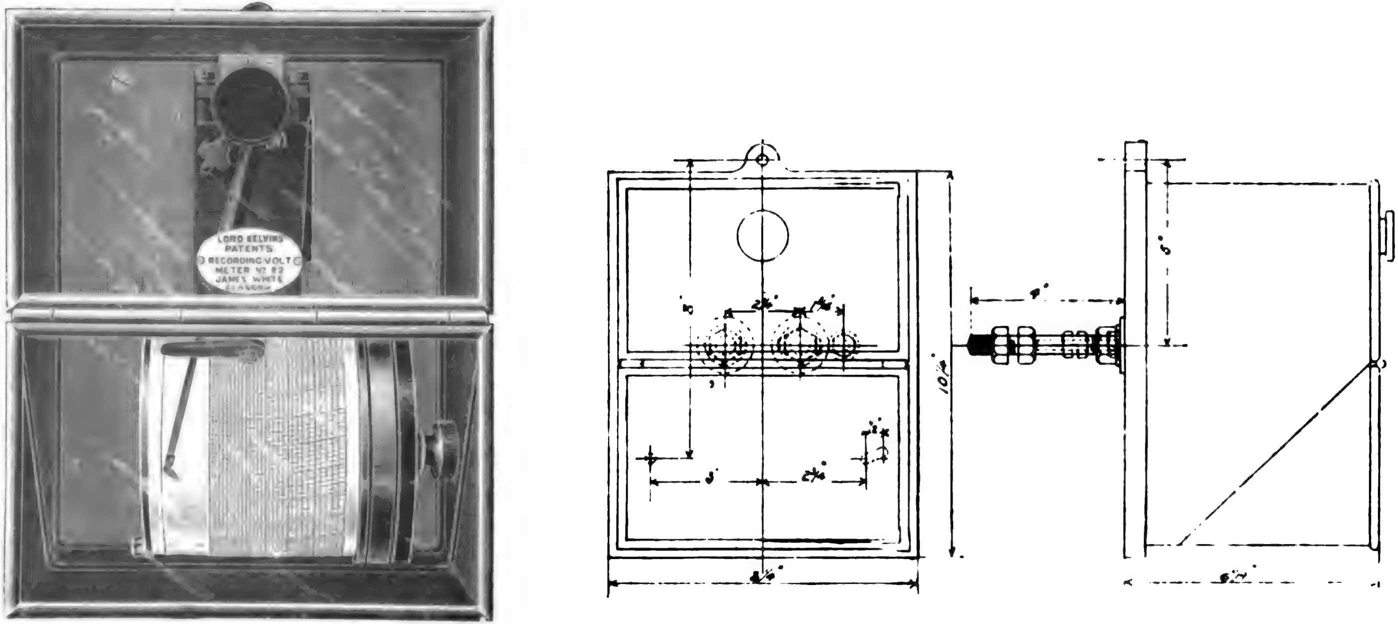


FIG. 25.—Recording Wattmeter.

is the same in principle as the wattmeter described above. The fixed coils are placed in a horizontal plane, and when the plane of the movable coils is at right angles to the plane of the fixed, the pointer is about 20° lower than the middle point on the scale. With the coils and pointer thus relatively placed the scale obtained is almost perfectly uniform. The record sheets are designed to show a variation of 20 per cent. on each side of the working voltage, this variation corresponding to a movement of the pointer on either side of 12°. The external non-inductive resistance consists of electric glow lamps. The filaments of the lamps which are arranged in series with the coils of the instruments not only act as resistances, but owing to the temperature variation of carbon being opposite to that of copper, compensate for any change in the resistance of the coils due to temperature. The current through the lamp filaments brings them to dull red, and under these conditions the resistance is found to remain quite permanent.

The recording wattmeters (Fig. 25) differ from the astatic recording voltmeters in that the fixed coils are of copper ribbon and carry the main current, while the movable coils, with electric lamps in series with them, take the shunt current. Each coil of the two movable coils is wound with 93 metres of No. 33 copper wire. The number of turns is 1,770, and the resistance of each coil is 89 ohms. Each of the two fixed coils is wound with 146 metres of No. 38 copper wire, and has 996 turns and 140 ohms resistance. The resistance of the lamps put in series with the coils depends upon the voltage at which the instrument is required to work. The mean working current through the instrument and lamps is arranged to be about one-eighth of an ampere. With this current the working force at the middle of the scale is approximately half a gramme weight.

I have to thank Mr. Charles A. Pulsford for information regarding the coils of the wattmeters, and for the trouble he has taken in arranging the instruments on the lecture table for the convenient inspection of the members present at the meeting.

Kelvin's electric measuring instruments may be also classified as follows, and the more important of them enumerated :—

I. Standard Instruments.

1. Ampere Balances. Fig. 17.
2. Watt Balances.
3. Multicellular Electrostatic Voltmeters. Fig. 1.
4. Vertical Electrostatic Voltmeters. Fig. 2.
5. Quadrant Electrometers.
6. Absolute Electrometers.

II. Portable Instruments.

1. Horizontal Multicellular Voltmeters.
2. Portable Suspended-Coil Amperemeters and Voltmeters. Fig. 12.
3. Testing set for measuring insulating resistance.
4. Cell Tester.
5. Rail Tester. Figs. 11 and 12.
6. Paralleling Voltmeters. Fig. 9.
7. Graded Galvanometers for currents and potentials. Fig. 5.
8. Portable Electrometers.

III. Central Station Instruments.

1. All the Electrostatic Voltmeters. Figs. 1, 2, 3.
2. The Suspended - Coil Voltmeters and Amperemeters. Figs. 6, 7, 8, 9, 10, 11, 12.
3. The Ampere Gauge Recording Voltmeters and Amperemeters, including the Feeder Log. Figs. 13, 14, 15, 16, 22, 23, 24.
4. Earth Current Recorder.
5. Astatic Recording Voltmeter for Alternating Currents.
6. Recording Wattmeters. Fig. 25.
7. All the types of Ampere Gauges. Figs. 13 to 16.
8. Engine-room Wattmeters. Figs. 18 to 21.
9. Three-phase Wattmeters.
10. Rail Tester. Figs. 11 and 12.

APPENDIX I.

Patents Relating to Improvements in Apparatus for Generating, Regulating, Measuring, Recording, and Integrating Electric Currents.

Number of Patent.	Date of Provisional Specification and of Complete Specification.	Title of Patent.	Number of Pages.	Number of Sheets.	Number of Figs. or Diagrams.
3,032	July 9, 1881 Jan. 9, 1882	Improvements in regulating electric currents, and in the apparatus or means employed therein	11	3	9
5,668	Dec. 26, 1881 June 28, 1882	Improvements in dynamo-electric machinery, and apparatus connected therewith	18	13	70 Lapse.
2,028	April 21, 1883 Oct. 20, 1883	Improvements in apparatus and processes for generating, regulating, and measuring electric currents...	28	25	48
4,617	Sept. 28, 1883 Mar. 27, 1884	Apparatus for generating, regulating, measuring, recording, and integrating electric currents... ...	41	18	36
4,655	Mar. 10, 1884 Oct. 8, 1884	New or improved suspensions for electrical incandescent lamps ...	4	1	2
5,355	Mar. 22, 1884 Nov. 10, 1884	Improvements in dynamo-electric machinery	3	1	5
6,410	Mar. 10, 1884 Oct. 28, 1884	Improvements in breaking electric contact to prevent over-heating by imperfect contact	3	2	6
10,530	July 24, 1884 April 25, 1885	Safety fuses for electric currents ...	7	1	13
11,106	Aug. 9, 1884 May 7, 1885	Improvements in apparatus for measuring electric currents ...	10	6	7
9,016	July 10, 1886 April 9, 1887	Improved apparatus for measuring efficiency of an electric circuit. (Amended October 4, 1897) ...	13	28	40
18,035	Dec. 11, 1888 Sept. 7, 1889	Electrostatic apparatus for measuring potentials	4	3	7
18,035a	Dec. 11, 1888 Sept. 7, 1889	An improved ampere gauge and connections...	3	3	6
18,035b	Dec. 11, 1888 Sept. 7, 1889	Improved apparatus for continuously measuring potentials or currents	3	2	3
15,769	Oct. 8, 1889 July 7, 1890	Apparatus for measuring and recording electric currents. (Allowed to lapse)	4	3	4
1,004	Jan. 20, 1891 Oct. 20, 1891	An improved indicator for electric potentials	2	1	3
18,436	Oct. 27, 1891 July 22, 1892	Improved apparatus for measuring and recording electric currents ...	5	3	6
10,230	May 30, 1892 July 2, 1892	An improved electric condenser ...	2	2	2
2,198	Feb. 1, 1893 Nov. 1, 1893	Improvements in balances	2	1	5
2,199	Feb. 1, 1893 Feb. 1, 1893	An instrument for measuring electric currents	3	1	4
5,733	Mar. 17, 1893 Dec. 16, 1893	Improved arrangement for reading the deflections of electric instruments	2	1	2
24,471	Dec. 20, 1893 Oct. 20, 1894	Improvements in electric supply meters	3	1	2

APPENDIX I.—*Continued.*

Number of Patent.	Date of Provisional Specification and of Complete Specification.	Title of Patent.	Number of Pages.	Number of Sheets.	Number of Figs. or Diagrams.
24,979	Dec. 29, 1893 Dec. 29, 1894	Improvement in instruments for measuring and recording electric pressures and currents	1	3	5
15,034	Aug. 7, 1894	Improvements in instruments for measuring electric currents ...	—	—	—
2,261	Nov. 27, 1895 Sept. 28, 1896	Improvements in apparatus for indicating and recording electric supply	5	1	2
18,438	Aug. 9, 1897 May 9, 1898	Improved coil for electric instruments	3	1	5
21,716	Oct. 15, 1898 July 14, 1899	Improvements in electric measuring instruments...	2	1	1
3,937	Mar. 1, 1900 Dec. 1, 1900	Apparatus for indicating and recording electric pressure and current	3	1	4

APPENDIX II.

PATENTS RELATING TO IMPROVEMENTS IN TELEGRAPHIC APPARATUS.

Number of Patent.	Date of Provisional Specification and of Complete Specification.	Title of Patent.	Number of Pages.	Number of Sheets.	Number of Figs. or Diagrams.
329	Feb. 20, 1858 Aug. 19, 1858	Improvements in testing and working electric telegraphs	36	1	9
329	May 19, 1871	Disclaimer.	19	—	—
2,047	Aug. 25, 1860 Feb. 25, 1861	Improvements in the means of telegraphic communication ...	37	4	27
1,784	July 6, 1865 Jan. 6, 1866	Improvements in electric telegraphs	14	1	9
2,147	July 23, 1867 Jan. 23, 1868	Improvements in receiving or recording instruments for electric telegraphs	10	1	7
3,069	Nov. 23, 1870 Not allowed.	Improvements in electric telegraph transmitting, receiving, and recording instruments, and in clocks	33	—	—
252	Jan. 31, 1871 July 31, 1871	Improvements in transmitting, receiving, and recording instruments for electric telegraphs ...	24	7	37
810	Mar. 25, 1871 Void.	Improvements in clocks and apparatus for giving uniform motion ...	4	—	—
2,086	June 12, 1873 Dec. 12, 1873	Improvements in telegraphic apparatus	14	4	11
1,095	Mar. 13, 1876 Sept. 13, 1876	Improvements in telegraphic apparatus	16	4	21
24,868	Dec. 28, 1895 Sept. 28, 1896	Improvements in recording instruments for telegraphic and other purposes	4	2	6

Mr. Chamen.

Mr. W. A. CHAMEN: I do not want to detain you for a moment, but I would like to say that the feeder log which has been described by Dr. Maclean was made at my request for the Glasgow Corporation. We have now about 100 of those instruments in daily use, and in the visits to-morrow to Port Dundas or to any other of the stations, members will be able to see the instruments in actual operation. They are a great advantage for central station engineers, because they show you at one and the same time the variations of the current and of the voltage upon the same sheet of paper. We file our records away, so that we can refer to them at a moment's notice, and we do not any longer continue the old-fashioned method of keeping the log figures in a book, where one has to rely upon the uncertainty of the human element. When it is realised, as I have said, that we have already over 100 instruments in use, I think engineers will begin to see how really valuable that instrument is likely to prove. There are some in the Exhibition, of course, which can also be seen. At Port Dundas before very long we shall have some sixty feeders, and the labour that would be entailed in taking readings both of volts and current on the three-wire system would be something terrific. These instruments dispense with the whole of that trouble.

The President.

The PRESIDENT: As there is no further discussion on Professor Maclean's paper, I will ask you to accord him a very hearty vote of thanks for his kindness in having so readily and lucidly drawn our attention to all the most important points in his paper.

The vote of thanks was carried by acclamation.

MEETING OF THURSDAY, SEPTEMBER 5th, 1901.

The PRESIDENT: Before calling upon Mr. Field to read his paper, I think it will be interesting to those present for me to give you some information with respect to the progress of the National Physical Laboratory which is now being established at Bushey House. Dr. Glazebrook, the Director of the Laboratory to whom I am indebted for the information, tells me that for the engineering work a room 80 ft. by 50 ft. has been built, and is being provided with travelling crane, and all necessary equipment for driving machinery for practical or experimental research. Adjoining are a drawing office and other rooms. Power is obtained from a 50 k.w. Parsons turbine. Dr. Glazebrook adds that the work which the Committee hope to attack in the first instance, is that which was commenced and has since been carried on by the Alloys Research Committee of the Institution of Mechanical Engineers.

Apparatus for the photo-micrographic examination of steel rails is being set up, while for the experimental ex-

amination of the elastic properties of alloys a specially designed testing machine is on order. Arrangement are also being made for testing pressure gauges and steam indicators. Provision will also be made for testing gauges of all kinds in use in engineering works.

Thanks to the generosity of Sir Andrew Noble, an excellent comparator, a dividing engine, and other measuring apparatus of the highest class will be available.

The measurement of electrical quantities of all kinds will form a prominent feature of the work.

The Superintendent of the Engineering Department will be Dr. T. E. Stanton, whose researches on the theory of surface condensers are already well known to engineers.

The Laboratory will be opened, the Committee trust, before the end of the year.

THE RELATIVE ADVANTAGES OF THREE-, TWO-, AND SINGLE-PHASE SYSTEMS FOR FEEDING LOW-TENSION NETWORKS.

By Michael B. Field, M.I.E.E., A.M.Inst.C.E.

In April last the Institution of Electrical Engineers did me the honour of asking me to read a short paper on the relative advantages of three-phase, two-phase, and single-phase power transmissions for feeding low-tension networks, to introduce the discussion on this subject in Section IX. of the Glasgow Congress.

In putting this paper before you, I wish to state that I have merely given expression to my own views on the subject, and have no idea whatever of dogmatically asserting that any one system is the best or the worst for a definite case. I have taken the Institution at their word, and have prepared a short paper in the hope that it may lead to a good discussion and call forth the views of other engineers more competent than myself to speak authoritatively on the subject.

To put my ideas in a few words, I must say that I completely fail to understand the objections of single-phase advocates to the three-phase system. For instance, in the case of a large tramway scheme I personally think that any

one of the three systems should give excellent results; but while the three-phase is not one bit more complicated (except, perhaps, in theory) than the single-phase, it possesses certain marked advantages from the point of view of prime cost, overall efficiency, and stability of operation, which should justify its general adoption for any such extensive schemes as that now being developed in Glasgow. Let us consider, then, the transmission of power from a single central station to a number of feeding centres sufficiently remote to render the adoption of high-tension alternating currents for the transmission an essential; and, further, let us assume that we are not restricted as to the choice of frequency. I do not propose to discuss here the possibility of working the tramway system with alternating-current motors. I fully believe that before long this will be possible, but at present it is certainly impracticable. An efficient motor capable of economical speed-regulation for city and suburban traffic, giving a large starting torque, and requiring but a single-sliding or rolling contact for conveying current into the moving vehicle has yet to be designed; and it, along with the accessory apparatus, will have to be standardised and subjected to severe tests over a lengthy period of time before railway engineers will be prepared to accept the same as a substitute for a continuous-current series motor.

Any one acquainted with the Glasgow system will recognise the utter impracticability of working with two overhead conductors at different potentials per track at the very complicated crossings and junctions which occur in the city, and also the great difficulty and heavy expense of constructing a conduit system for two conductors owing to the enormous number of gas and water mains under the surface of the main thoroughfares, while the very heavy traffic in the same would render a surface contact system unreliable. These facts alone, apart from all other considerations, strongly favour the adoption of the series motor. (See Note I.)

We have, therefore, no other choice than to assume substations and suitable converters at the feeding centres for transforming the high-tension alternating into continuous current at 500 volts. In dealing with the possible types of converter, I wish to refer to the very detailed paper entitled

"Polyphase Sub-station Machinery," read before the Institution of Electrical Engineers on March 14th of this year, by Mr. A. C. Eborall.

Generating and Transforming Machinery.—The choice of converter lies between (1) Rotary Converters combined with Static Transformers; (2) Synchronous Motor Generators without Transformers; (3) Non-synchronous Motor Generators without Transformers.

The relative outputs for the same C^2R loss of a rotary converter if used as a continuous-current generator, or a single-phase, three-phase, four-phase, or six-phase converter respectively, are as follows :—

D.C. Generator.	Single-phase Rotary.	Three-phase Rotary.	Four-phase Rotary.	Six-phase Rotary.
1·00	·825	1·31	1·61	1·94

The four-phase connections will be employed with the ordinary two-phase transmission system, the three- and six-phase rotary connections with the three-phase system, or possibly with a suitable arrangement of transformers with the two-phase system. The table is based on calculations only, and I am not aware that the figures have been verified experimentally; I see, however, no reason to doubt their accuracy.

Table I. (p. 141) has been taken from Mr. Eborall's paper, the last column, which refers to the Glasgow 500-k.w. rotary, having been added.

Table II. (p. 142) gives costs, together with a comparison of efficiency and weight, of three- and two-phase rotaries, three-, two-, and single-phase synchronous and non-synchronous motor generators for twenty-five cycles 500-k.w. output (this is the size of Glasgow Sub-station units).

TABLE I.

Type of Equipment.		Asynchronous Motor Generator.	Synchronous Motor Generator.	Rotary Converters and Step-down Transformers.	Glasgow Rotary.
Output of sub-station converter		500 kw.	500 kw.	500 kw.	500 kw.
Speed of converter ...		300	300	300	500
Number of field-poles (generator)... ...		10	10	16	6
Peripheral speed of commutator ...		1880	1880	3100	3250
Number of commutator bars		270	270	560	324
Temperature rise, any part after 24 hours at full load... ...		35°C.	35°C.	35°C.	30°C.* After 12 hours.
Efficiency	Full load	86%	87%	92%	92·5*
	Half "	80%	79%	87·5%	89·5*
Overload capacity for one hour with fixed brushes		25%	25%	75%	50%* Rise of T.=60°C
Power-factor	Full load	91%	100–96% (leading.)	100–96% (leading.)	—
	Half "	88%			
Starting current from A.C. side in terms of full load current		50% (Rotor resistance.)	100% (Starting motor.)	60% (Starting motor.)	—
Full load drop of speed		3%	None	None	None
Floor space required per kilowatt (square feet)...		0·5	0·5	0·45	0·34

* Figures marked thus are guaranteed by Contractors only.

TABLE II.

Type of Sub-station Converter.		Cost, including all necessary Starting Gear.	Total Weight.	Efficiency of Equipment. Full Load.	¾ Load.	½ Load.
		£	Tons.			
3-Phase Rotary with Transformers.	A	2,160	33	91	89·75	86·75
	B	2,560	31	92	90·5	88
	C	2,240	38	93·6	92·6	88·4
	D	2,122	40	—	—	—
2-Phase Ditto.	A	2,240	34	91	89·75	86·75
	B	2,580	32	92	90·5	88
	C	—	—	—	—	—
	D	2,114	—	—	—	—
3-Phase Synchronous Motor-Generator.	A	2,400	42	89·5	88·25	85·25
	B	2,280	44	86·5	85	81·5
	C	2,320	42	90	87	80
2-Phase Ditto.	A	2,400	42	89·5	88·25	85·25
	B	2,280	44	86·5	85	81·5
	C	2,320	42	90	87	80
Single-Phase Ditto.	A	2,500	44	88·5	87·25	84·25
	B	2,440	48	85	83	79
	C	—	—	—	—	—
	D	3,100	38	—	—	—
3-Phase Induction Motor-Generator.	A	2,680	50	89	87·75	84·75
	B	2,260	44	85·5	84·5	81·5
	C	2,360	43	89	86	80
2-Phase Ditto.	A	2,680	50	89	87·75	84·75
	B	2,300	45	85	84	81
	C	—	—	—	—	—
Single-Phase Ditto.	A	3,200	64	85	83·75	81
	B	2,580	52	80	77	72
	C	—	—	—	—	—

N.B.—All the above refer to converter equipments of 500 k.w. output at 500 to 550 volts on the D.C. side. Input at 6,500 volts on A.C. side. To each equipment is direct-coupled a negative booster, 600 amps. at 50 volts for rail return cables, *i.e.*, Glasgow Practice, and where necessary a starting motor. A, B, C, refer to different makers.

The single-phase rotary works at such a disadvantage compared with two- and three-phase rotaries, that I have not thought it worth while to include it in the above table.

From these figures it is evident that the rotary converter *per se* has the advantage over all other converters. It is true it requires three or six extra single-pole low-tension switches on the switchboard, but in itself is a less complicated machine than the motor generator.

Taking it altogether, there is, as regards complication, nothing to choose between a rotary with its transformers and a motor generator without. As regards ease of running and starting up, I would say that, with properly designed rotaries for low frequency, there is no difficulty in this respect. Much is talked about surging and hunting of rotaries; almost exactly the same may occur with synchronous motors; but in all well-designed machines of both types, driven from good generators coupled to well-designed engines, giving a uniform turning moment, with heavy fly-wheels, this trouble may be considered as practically non-existent.

Lastly, as regards overload capacity, ease of regulation and manipulation, the rotary converter affords all that can be desired. The Glasgow rotaries, for example, have from the moment they were first started run without trouble of any kind. It is, of course, *possible* to make them surge, but it is not easy. Curves *a* and *b*, Fig. 6, show the voltages taken with recorders on the D.C. side of rotary. Perhaps the only trouble we have had at all has been the reversal of the polarity of the rotaries, due to a heavy surge of current throughout the system, which has occurred once or twice on switching out a generator. As a matter of fact, this has not caused us any inconvenience to speak of, as the cars do not know or care whether the trolley wire above them is positive or negative. It would not do if we were charging cells, but in any case I think it is a difficulty which we shall readily overcome as we become more experienced.

Cables.—It is interesting to note that theoretically the three-phase system should give the best results as regards power that can be transmitted with a given weight of copper and with a minimum strain upon the insulation of the system.

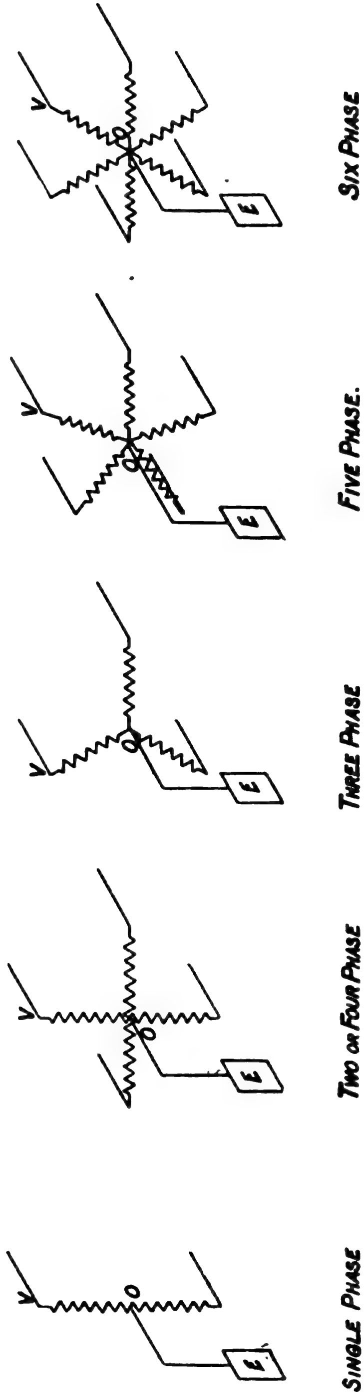

SIX PHASE
FIVE PHASE.
THREE PHASE
TWO OR FOUR PHASE
SINGLE PHASE

FIG. 1.

Figure 1 represents systems involving the single-, two- or four-, three-, five-, and six-phase principles, the neutral point in each case being earthed. Let V be voltage and C current per leg in each system (in the single-phase case the line voltage equals 2V), then the power transmitted in the different cases will be represented by nVC cos ϕ, where n = number of legs, and ϕ = angle of lag. The power transmitted per unit weight of copper will be the same in each case, and similarly the maximum potential above earth; but the maximum potential difference existing between any two points in the system (*e.g.*, between the cores of a line cable) is a minimum in the three-phase case. Again, if the neutral point be not earthed, we must consider as the maximum strain on the insulation, the voltage above earth of any line-wire or pole if one other become accidentally earthed for an instant; this is again clearly a minimum in the three-phase case.

Consider a specific case. In Glasgow we have four three-core cables to each of the five sub-stations; the area of these cables is 0·1 or 0·15 square inch per core, as the case may be. Any one of these cables may be switched out independently of the others. An equivalent arrangement, if single-phase transmission had been adopted, would have been obtained by employing—

(1) One concentric cable per circuit, or four cables per sub-station.
(2) Two independent single-core cables per circuit, or eight cables per sub-station.
(3) One two-core cable per circuit, or four cables per sub-station.

In the case of a two-phase transmission we might have corresponding arrangements with—

(1) Two concentric cables per circuit.
(2) Four single-core cables per circuit.
(3) Two two-core cables per circuit.
(4) One four-core cable per circuit.

In comparing the various systems, we can either keep the maximum potential above earth the same in each case—in other words, keep the same strain upon the insulation of

generators, etc.; or we can keep the difference of potential between the line-conductors, that is, the strain on the insulation of the cables, the same in each case. It does not, however, follow that these two conditions will obtain at the same time.

Table IV. gives a comparison of these various cable systems, taking as a basis one mile of three-core cable with earthed neutral, transmitting 1,000 kilowatts at 6,500 volts (three-phase), the area of each core being 0·15 square inch. In every case the effective voltage is referred to, not the maximum of the voltage-wave curve.

In the above case it will be seen that the strain on the insulation of generators, transformers, etc., is 3,750 volts, and on the insulation of the cables 6,500 volts.

Cases 2 and 3 represent a single-phase transmission with concentric cables. In this instance it will be essential to work with an earthed outer conductor to ensure stability of working. With 3,750 volts between inner and outer we shall have the same strain on the insulation of the generators, but a smaller strain on that of the cables. With 6,500 volts working-pressure the strain on the generators will be greater, and on the cables the same as in Case 1. The amount of copper in the line will be four times and 1·33 times respectively that in Case 1 for the same transmission loss.

Cases 4 and 5 represent a single-phase transmission with two-core cables, the neutral point being earthed. In Case 4, with 1·33 times the amount of copper, we have the same strain on cables but smaller strain on generators; with the same copper in the line (Case 5), we have the same strain on the generators but a greater in the cables.

Case 6 represents a single-phase transmission with two separate cables and an earthed neutral. In this instance the working voltage should be 7,500, when the strain on both generators and cables will be 3,750, the weight of copper being the same as in Case 1. The disadvantage is, of course that twice the number of actual cables is required, and the self-induction of the line materially increased.

Cases 7 and 8 represent two-phase transmissions with four-core cables and earthed neutral points. They exactly correspond to the single-phase Cases 4 and 5, and to Cases 9 and 10, where two two-core cables per circuit are employed.

TABLE IV.

1000 K.W. transmitted one mile through—	Volts between line wires or cores.	Volts per leg of system.	Current per line wire.	Area cross section per line wire.	Total area cross section.	Volts above earth of any line wire, *i.e.*, electrical strain on generators, switch gear, etc.	Volts between cores, *i.e.*, strain on insulation of cable.	Cost per mile laid and jointed, including ducts and drawing in. A.	B.
								£	£
(1) 3-phase, 3-core; earthed neutral point of system	6,500	3,750	89	·15	·45	3,750	6,500	956	1,072
(2) Single-phase concentric; earthed conductor	3,750	—	267	·9	1·8	3,750	3,750	2,244	2,154
(3) Ditto, ditto.	6,500	—	154	·3	·6	6,500	6,500	1,150	1,499
(4) Single-phase, 2-core; earthed neutral	6,500	3,250	154	·3	·6	3,250	6,500	1,090	1,175
(5) Ditto, ditto	7,500	3,750	133	·225	·45	3,750	7,500	968	1,067
(6) Single-phase, two separate cables, outer earthed neutral	7,500	3,750	133	·225	·45	3,750	Strain on insulation 3,750	1,128	1,280
(7) 2-phase, 4-core; earthed neutral ...	6,500	3,250	77	·15	·6	3,250	6,500	1,132	1,256
(8) Ditto, ditto	7,500	3,750	66·5	·1125	·45	3,750	7,500	948	1,182
(9) 2-phase, two 2-core cables, earthed neutral	6,500	3,250	77	·15	·6	3,250	6,500	1,540	1,482
(10) Ditto, ditto	7,500	3,750	66·5	·1125	·45	3,750	7,500	1,352	1,374
(11) 3-phase, 3-core; not earthed ...	6,500	3,750	89	·15	·45	6,500	6,500	1,144	1,168
(12) Single-phase, 2-core; not earthed...	6,500	3,250	154	·3	·6	6,500	6,500	1,204	1,284
(13) Single-phase, two separate cables; not earthed...	6,500	3,250	154	·3	·6	6,500	6,500	1,420	1,456
(14) 2-phase; 4-core	6,500	3,250	77	·15	·6	6,500	6,500	1,240	1,388
(15) 2-phase; two 2-core	6,500	3,250	77	·15	·6	6,500	6,500	1,692	1,590

The above prices refer only to paper insulated, lead-covered cables, drawn into cement-lined iron ducts (*i.e.*, Glasgow Practice). In each case the same power is transmitted, and the loss per mile in kilowatts is 6·3.

Case 11 represents the three-phase three-core case where the neutral is not earthed; here we have, of course, as maximum possible strain on generators and cables, 6,500 volts. With this we may compare the systems with two-core, four-core, and separate cables. In this instance the strain on both generator and cables, as in Case 10, will be 6,500 volts, but the weight of copper will be increased by 33 per cent.

This is a somewhat lengthy discussion on the cable question, but I think it includes all possible cases, and the basis of comparison is a fair one. The last column of the table giving costs applies to lead-covered paper-insulated cables, and includes the cost of duct laying on the system adopted in Glasgow; the table clearly shows that the advantage certainly lies with the three-phase system. It has been assumed throughout that in the single-, two-, and three-phase cases the shape of the E.M.F. wave will be the same, and I see no reason why it should not be so.

Before dismissing this cable question, I would like to say that I personally much prefer to have an unearthed system, and to rely on keeping a proper check on the insulation. If concentric cables be employed, it is imperative to earth the outer conductor. I think a three-core cable is the handiest and best.

Of course, if other side issues enter in here, such as Board of Trade requirements in the way of earthed metallic sheaths outside the cables and distinct from the lead covering, or limit of power to be transmitted through any single cable, the above considerations may be entirely modified. For example, the two-phase and single-phase systems require the same weight of copper as long as each phase is supplied through a two-core cable and the systems are unearthed; the two-phase system with a three-conductor cable is much more extravagant from the copper point of view than the single-phase, but if we have to provide an earthed sheath, and we utilise this as one conductor, the two-phase with two concentric cables requires less copper than the single-phase with one concentric cable, since in the former case the two outers being connected by earth form a common main, and hence their cross-section can be reduced.

TABLE V.

Type.	Volts per phase.	Current.	Area.	Loss total.	Max. possible strain on insulation of system.
				Per mile.	
Single-phase, two-core, or two separate cables—unearthed system...	6,500	154	·3 + 3 = ·6	6·3 k.w.	6,500
Two-phase, three-conductor, with or without common conductor earthed	4,600	109 109 154	·256 + ·256 + ·362 = ·874	6·3 k.w.	6,500
Single-phase, concentric, earthed outer	6,500	154	·3 + ·3 = ·6	6·3 k.w.	6,500
Two-phase, 2 concentric earthed outers	6,500	77 77 109	·128 + ·128 + ·181 = ·437	6·3 k.w.	6,500

The above table illustrates this, showing how the question of Board of Trade regulations may entirely modify one's views. Note that the three-phase system with earthed neutral is considerably better than the two-phase with two concentrics. In the former case the copper area is ·45, and strain on generators 3,750; in the latter, copper area is ·437, the strain on generators being 6,500 volts, or twice as many cables are required as in the three-phase case.

Switchboards.—Here alone will a simplification be effected by employing a single-phase circuit. The mere fact, however, of requiring three legs per switch instead of two, or possibly, though not necessarily, three ammeters per circuit instead of one, should not have very much weight in determining the choice of a system. I may say that in the Glasgow scheme all switchboards put together constituted only about one-fifth of the value of the cable system, so that the saving effected here by the employment of a single-phase system could not have amounted to much.

In this connection there is one thing to be said in relation to the space question: it is often extremely difficult to fit in a switchboard; for a large scheme particularly the

boards may assume such proportions as to cause considerable difficulty in making an entirely practicable arrangement, and any system which will diminish the overall dimensions of the board *safely* will in that respect have the advantage.

Generators.—I have obtained from different makers, for the purpose of this paper only, prices of three-phase and single-phase generators corresponding in type and output to the Glasgow 2,500 k.w. units. The particulars given to each maker were as follows :—

Output, 2,500 k.w.
Voltage, 6,500.
Efficiency full load, 96 per cent.
Three-quarter load, 95 per cent.
Half load, 93 per cent.
Speed, 75 revolutions.
Cycles, 25.
Fall of pressure between full load and no load, at constant speed and excitation, and power factor unity, to be not more than 7 per cent.
Generator to be supplied without outboard bearing, or shaft, but with bed-plate rheostat, etc.

In Table VI. I have attempted to tabulate the figures obtained from the various makers, from which it is at once evident that the three-phase generator is cheaper and lighter than the single-phase.

TABLE VI.

GENERATORS TO SPECIFICATIONS AS ABOVE.

	Three-phase.		Single-phase.	
	Weight.	Cost.	Weight.	Cost.
(1)	123 tons.	£6,000	184 tons.	£8,900
(2)	120 tons.	£5,400	140 tons.	£6,200
(3)	110 tons.	£4,600	125 tons.	£5,200
(4)	92 tons.	£5,360	105 tons.	£6,080

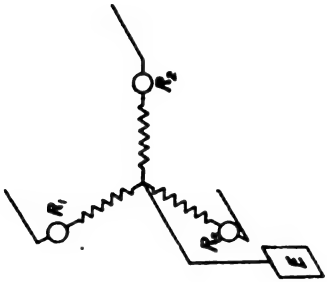


FIG 4.

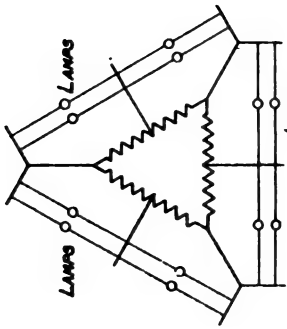


FIG 3.

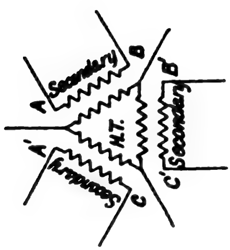


FIG 2.

While the foregoing considerations, in my opinion, point conclusively to the fact that a three-phase plant is the best for operating a large tramway system such as that of Glasgow, I confess that I am not such an out-and-out advocate of the three-phase principle as to recommend its adoption where the principal load consists of light pure and simple.

The single-phase motor has of late made great strides, and is now a thoroughly practical and fairly economical machine, so much so, in fact, that taking into account the improved design of single-phase generators and methods of automatically compounding the same, a very considerable motor load may be connected to single-phase lighting circuits without detriment (Notes II. and III.).

At the same time improvements are going on all round, and while a considerable motor load may be attached to single-phase lighting circuits without injurious effects, lights may perfectly well be, and in a large number of cases are, connected to three-phase motor circuits with excellent results. It is interesting to note, however, that the saving of copper in the low-tension network where the three-phase system is adopted is, contrary to expectation, practically nil.

Figure 2 represents a three-phase transmission with three single-phase distribution circuits on the low-tension side. The low-tension network then exactly corresponds, as regards weight of copper, to a single-phase distribution network.

Now imagine that A and A′, B and B′, C and C′, are grouped together, the area of each of the three mains now being 1·73 times that of A, B, C, A′, B′, C′ taken separately; in each of the three mains we shall have 1·73 times the current, that is the same current density as before, and hence the same drop per mile; in other words, while we distribute the same amount of power, we reduce our weight of copper 13½ per cent. and lessen the distribution losses by an equal amount. This consideration seems to point to a great advantage in the three-phase distribution; but this is not really the case, for in the single-phase distribution a three-wire system would certainly be adopted; the corresponding three-wire three-phase system as represented in Fig. 3 would, it is true, compare favourably as to saving of copper with the single-phase three-wire system; it is, however, an impracticable method, owing to the multiplicity

of inter-connected circuits and the difficulty involved in the independent regulation of the same. The only method which corresponds to the three-wire single-phase, and is at the same time at all feasible where independent regulation of the various circuits is desired, is represented in Fig. 4, where R_1, R_2, and R_3 are series-shunt regulators.

If, then, the lamp voltage or voltage across one leg of the system be made equal to the voltage between the outers and the neutral of the single-phase three-wire system, the total voltage between the outers of the latter system will clearly be greater than the voltage per phase in the three-phase distribution; in other words, since the lamp voltage is to be the same in either case, the voltage per leg must also be the same, which means that, provided the neutral wire in each

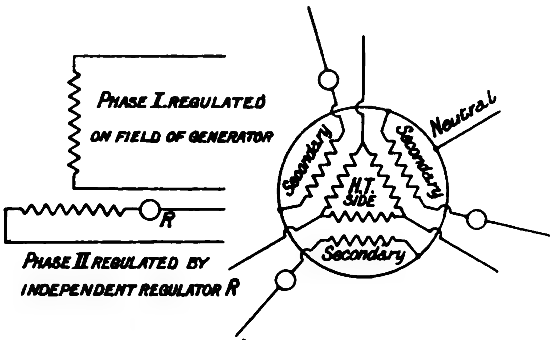


Fig. 5.

has the same cross-section, the total weight of copper for a given output and percentage loss will be the same for each. On these grounds I think that the adoption of two-phase plant where the transmission losses are necessarily small, and where both power and light are supplied from the same circuits, is warranted. A further advantage is that it is possible to regulate the phases independently of each other in the generating station, if this be required, with the two-phase system, while with the three-phase system it would be necessary to insert regulators in the low-tension mains at the sub-stations (see Fig. 5).

The effect on the one phase by the variation of load on the other is, as far as I have been able to ascertain, not materially different with a two-phase or three-phase generator. Roughly speaking, if $x\%$ is the drop on a

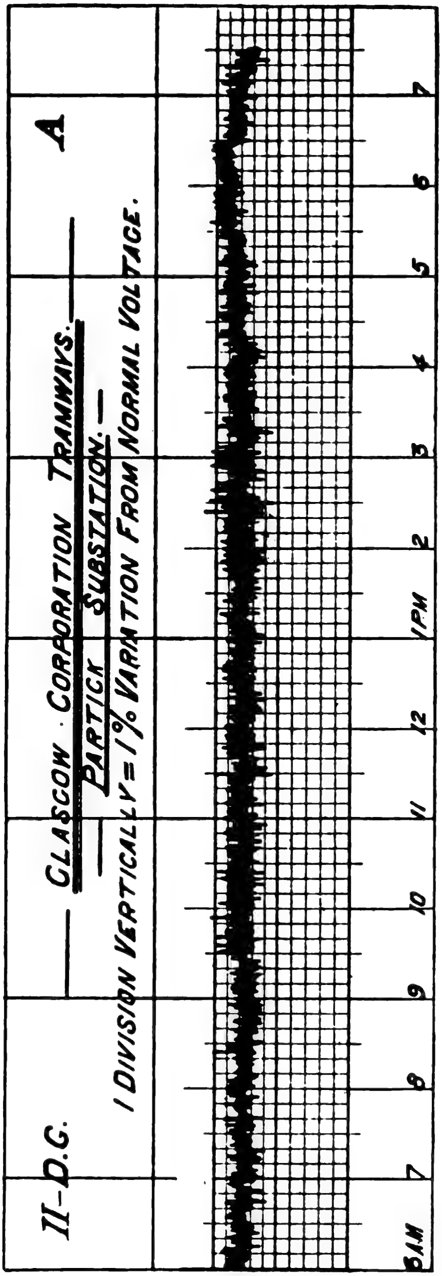
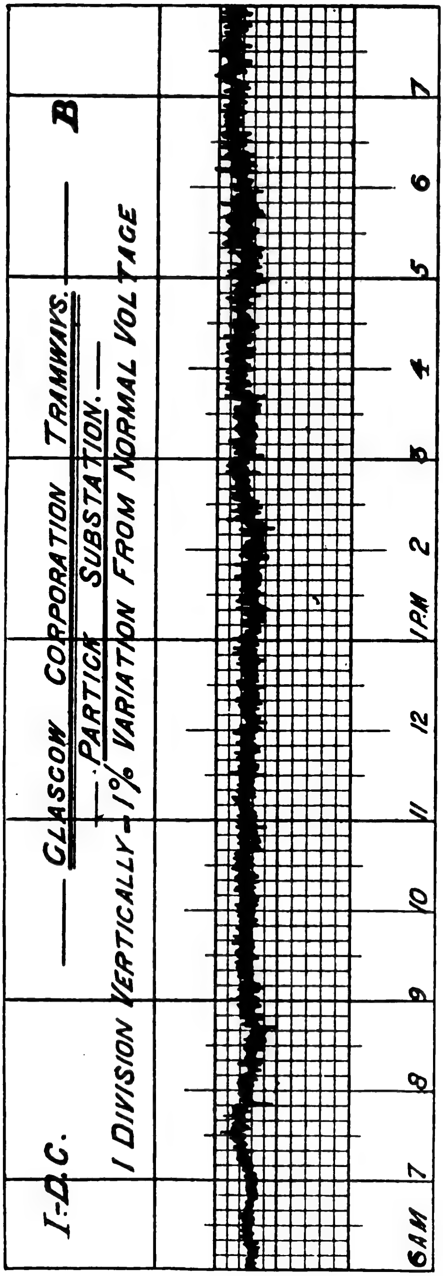

II-D.G.
GLASGOW · CORPORATION TRAMWAYS.
A
PARTICK SUBSTATION.
1 DIVISION VERTICALLY = 1% VARIATION FROM NORMAL VOLTAGE.
6 A.M.
7
8
9
10
11
12
1 P.M.
2
3
4
5
6
7

FIG. 6A.


I-D.C.
GLASGOW CORPORATION TRAMWAYS. B
PARTICK SUBSTATION.
1 DIVISION VERTICALLY = 1% VARIATION FROM NORMAL VOLTAGE
6 A.M.
7
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12
1 P.M.
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6
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Fig. 6b.

non-inductive full load of a two-phase machine, and one phase be suddenly switched out, the voltage on the other phase will not alter by more than ·7 of x%, or if y be the drop on full load inductive current, the variation will be ·8 of y%.

In America a three-phase system[1] has been adopted of late with considerable success, where, to avoid all regulation in sub-stations and the like, the voltage of one phase alone is kept constant in the generating station, and the whole of the incandescent lights of the system are connected across this one phase. In such cases all incandescent lamps are connected across phase I., which is kept at constant pressure by regulating the field of the generator. Phases II. and III. will be used, say, for series arc lighting or for other purposes where a constant voltage is not an essential, while motors are connected across all three phases. In such a case the incandescent lighting may be supplied from a three-wire system, the neutral wire being connected to the middle point of the regulated phase, thus giving twice the lamp pressure as the working voltage between the motor terminals. When such a system is adopted, no attempt is made to obtain anything like balance of load on the three phases, it being claimed that any well-designed three-phase generator may be used up to 75 per cent. of its rated output as a single-phase generator, using two of the legs of the winding as the single phase; this means that when used as a single-phase generator, 30 per cent. more current may be taken from the loaded phase than the normal current rating per phase.

It appears to me, however, that as we begin to use two conductors as a single phase, we destroy the essence of the economy of the three-phase transmission, and hence, that a two-phase transmission with four-core cables would be just as advantageous. In this case the regulation might be done only on the one phase, all incandescent lighting being supplied from this phase; or both phases might be independently regulated in the generating station.

It is worthy of note that two- and three-phase motors and transformers, if connected to circuits of unbalanced

[1] Since reading this paper, Mr. C. E. L. Brown has called my attention to the fact that this system was adopted by him for the old Schwyz installation, and later was employed by his firm at Berne and Hageneck.

load, will tend to equilibrate the same, that is, they will tend to draw more load from the unloaded and less from the loaded phases. For instance, if a number of motors be connected to a two-phase circuit supplied from a two-phase generator, and while a number of motors are running, one phase circuit be opened at the generator, the motors, while in reality only receiving single-phase current from that phase still connected to the generator, will apparently run as two-phasers ; that is to say, they will be self-starting and found to have about ·8 of the normal voltage across the switched-out phase—in fact, the lightly loaded motors will be generating and circulating among the more heavily loaded motors the necessary currents in the switched-out phase, to enable them to work more as two-phase motors than as single phasers. Lastly, I wish to thank the firms of Messrs. Witting Brothers, Ltd., The British Thomson-Houston Co., Ltd., The International Electric Co., Ltd., of Liege, Messrs. Brown, Boveri & Co., The British Insulated Wire Co., Ltd., and The National Conduit and Cable Co., Ltd., for their kindness in providing me with the figures embodied in the various tables of this paper.

NOTE I.

It appears to me that if ever three-phase motors are to be successfully employed for tramway work in crowded cities, the solution of the problem will be found in the combination of two shallow conduits of the slot-rail type with surface contacts ; by this I mean such shallow conduits as would avoid contact with underground gas and water mains, but sufficient to afford protection to a number of contact studs laid, let us say, every two or three feet apart, in the floor of each conduit. These studs would be of the simplest character possible, involving no mechanism whatever, with the exception, say, of every fortieth, which would be of the present automatic surface contact type, and would control the succeeding thirty-nine. The automatic switches need not necessarily be placed under the road bed at all, but might be enclosed in boxes under the pavement, or several grouped together and erected in switch pillars and placed at intervals along the route where their accessibility would be a great point in favour of the scheme. Each car would carry two short skates of, say, 3 feet length, which could be easily introduced into the conduits at special boxes, and owing to their shortness, would ride easily round curves. Such a system, in my opinion, promises to obviate the dangers of the surface contact, and the difficulty of maintaining good insulation in the conduit system, together with the necessity of removing gas, water, and other mains.

NOTE II.

In Frankfurt at the present time there are from 500–600 single-phase motors connected to the mains, with an average of about 10 H.P. each. The total kilowatts output may be classified as :—

Motors	3,427	K.W.
Motor-generators	1,736	"
Lighting	6,482	"
Street ditto	123	"
In Station itself	91	"
Total	11,859	K.W.

The variation does not exceed ± 3 volts, the supply voltage being 120, and the frequency 45.

The lamps and motors are all connected to the same machines, feeders, etc. The motor-generators for traction purposes are usually operated separately, *i.e.*, from separate machines and separate feeders, but on Sundays the whole load, including traction load, is taken from the same generators, switchboard, and feeders.

NOTE III.

Table showing comparison of best single-phase motors and three-phase motors of small sizes :—

POWER FACTOR SINGLE-PHASE.	Full.	Half.	POWER FACTOR THREE-PHASE.	Full.	Half.
1 B.H.P.	0·7	0·53	1 B.H.P.	0·8	0·63
5 "	0·75	0·6	5 "	0·84	0·68
10 "	0·8	0·62	10 "	0·85	0·69
20 "	0·8	0·62	20 "	0·87	0·70

NOTE IV.

Experiments on a three-phase generator loaded on three-phase motor, two phases being loaded on a non-inductive resistance as well. Generator and motor both Y connected ; speed and excitation of generator kept constant.

Volts on Generator.			Motor Load : Amperes.			Non-inductive Load in	
Phase I.	Phase II.	Phase III.	Phase I.	Phase II.	Phase III.	Phases I. & II.	
133	132·8	130·5	0	0	0	0	
127·6	126·5	136·1	—	—	—	90	
126·4	126·0	137·0	—	—	—	104	
126·5	126·5	126·0	77·4	78·2	78·2	—	Motor loaded.
124·2	122·5	130·5	28·2	31·8	15·0	91·5	Motor running light.
121·5	122·5	128·5	87·4	70·8	67·8	87·0	Motor loaded.

The PRESIDENT: The subject dealt with in Mr. Field's paper is, it is needless to say, an exceedingly important one at the present juncture, when we are about to lay down extensive power-stations from which the distribution must be exceedingly large. The question of cables is therefore a most important one for consideration. The President.

Herr E. KOLBEN (*Prague*): I have to congratulate Mr. Field on his excellent contribution to the discussion on this most important question of the relative merits of the three-, two-, and single-phase systems. I must confess that I never saw such full information in regard to the cable question connected with alternate-current work as is given in this paper. The figures which Mr. Field gives in the paper are, in my opinion, perfectly correct, and show actually the advantage of the three-phase as compared with the two- or single-phase systems. I am the more pleased to see that Mr. Field's figures come out in this way as I have been advocating the three-phase system since 1892, when the first large three-phase plants were put into operation on the Continent; and I think that this system will come out as the final system not only for power distribution, but also for lighting combined with motor supply, as is usual in large cities. A very interesting point dealt with by Mr. Field is the employment of three-phase motors in railway work. I agree perfectly with him when he says that *at present* the three-phase motor is not suitable for tramway work as usual in large cities; but of course its field is the long main railway; and I think that for long-distance railways the three-phase railway motor will certainly come to the front. But there is no question, however, that the combined three-phase and continuous-current distribution as applied at the present time in large metropolitan areas, as, for instance, for the railways in Glasgow or London, is at present the right thing. I do not think that the three-phase railway motor will be suitable, for instance, for such an installation as the proposed system of the Metropolitan Railway in London. In this connection I would point out that the regulation of speed has a good deal to do with the question. In the three-phase motor, as it is started and regulated at present, a very large amount of energy is lost in speed regulation. In the year 1889 or 1890, when electric tramways began to come in America, they made no headway until the proper speed-regulation was fixed. Until the series-parallel control of the motors came in, it was necessary to make the power-stations about 20, 30, or 40 per cent. larger than required, because there was a very large amount of energy lost in regulating. And the same is the case at present with the three-phase motor. If we have to regulate with resistances only, we lose a large percentage of the energy, and we are obliged to make the power-stations 20, 30, or even 40 per cent. larger. The steam engine and the boiler plant will become so much larger, as also the engine-house, foundations, and everything. If you take, on the other hand, a plant with a three-phase generating station and converting sub-stations, the cost of the sub-station machinery will probably not amount to one-third of the extra cost that will have to be put in for the increase in size of plant owing to the regulation of the three-phase motor system, quite apart from the question of economy. For combined light and power distribution in large cities the three- Herr Kolben.

Herr Kolben.

phase system is also the right thing, but there a higher periodicity—42 to 50 periods—is required.

We have, for instance, in Prague a large three-phase station where we have taken 50 periods so as to enable us to supply not only the power for the tramways, but also the whole incandescent and arc lighting for the public and private supply from one station only, and from one set of 'bus-bars ; in short, the whole of the necessary electrical energy for the city. You cannot imagine a more simple plant than this. There we have a set of large generators of 1,000 or 3,000 H.P. units, we supply the whole energy to one set of 'bus-bars, and from those we distribute it to the different sub-stations and feed also the low-tension net-work for lights and motors. The low-tension net-work in such a case will be best made so that the connections are directly taken from the three ends of the three-phase low-tension cables. Although Mr. Field points out quite clearly the advantage of the connections with four cables, including the neutral in his diagram Fig. 4, there is not shown the direct distribution from the three ends of the secondary net-work, as is now being generally used on the Continent. Of course a three-phase and three-wire system as shown in diagram Fig. 3 would be altogether too complicated. I wish also to point out that the tests given in Note IV. to show the variation of pressure in the generator, two of the phases being on a non-inductive load, whilst the other phases are carrying motor load, are taken from too small a machine, so that they do not show actually favourable figures as to pressure regulation. But, according to my experience, it is a very small matter as to difference of pressure if one or two of the phases of a large generator or of a group of transformers of a larger size is loaded more than the other phases, even up to 30 per cent. difference of non-inductive load. If there is even 30 per cent. difference in the load between the phases, it makes a very small percentage difference of pressure between the phases, so that no special regulating devices are needed in the different circuits.

In conclusion, I would congratulate Mr. Field on his new idea as embodied in Note I. in regard to a system of conduit for a three-phase tramway in cities. I think that is a very good suggestion for future development, and should be well considered by every one connected with electric tramways.

Professor Carhart.

Professor H. S. CARHART (*Michigan*) : I have only glanced over the paper very briefly, and I am not able to make any real contribution to it. It is a very interesting paper on a very interesting subject. I can only say that, so far as I am aware, the systems for power-transmission in the United States now are, I think, going to be three-phase very generally. That is my impression. The two-phase is too little used for me to form a judgment from my observation.

With regard to frequency, it is possible for both lighting and power-service, it seems to me, to use a frequency below 50. I noticed only two or three weeks ago at the Buffalo Exhibition, where 5,000 H.P. is transmitted (the frequency being 25) from Niagara to the Exhibition Court for lighting purposes alone, that it is scarcely possible, without very careful watching, to detect any variation in the luminosity of the

lamps; so that a little above 25 the variations would, I think, be entirely invisible. For arc lamps on the same system I suppose a somewhat higher frequency would be desirable. But of course it is well known that for power-service the lower frequency is best. I observe in a number of our cities the open arc-lamp is giving way very rapidly to the enclosed alternating current lamp, and it is possible to run these in series on a three-phase distribution. The method of transferring from the older system to the newer one is rather interesting too. It is done, in some instances at least, by using three-phase or synchronous motors to furnish power to run the direct high-tension generators for arc-lamps for the transition period. But as soon as the older lamps are disposed of or the system is made over, then, of course, the whole work and load can be put on to the mains or the transformers of the three-phase distribution. It is rather interesting as a transitional arrangement. Professor Carhart.

The PRESIDENT: Is that due to the introduction of the enclosed lamp, do you think? The President.

Professor CARHART: Yes, the open arc-lamp in the United States is disappearing. One rarely sees it now, except in old installations. So far as I know, all the new installations are employing enclosed arc-lamps, either direct-current or alternating. Professor Carhart.

Mr. W. B. ESSON: I am sure the Section is very much obliged to Mr. Field for his excellent paper on the relative advantages of currents of different phases. I think it is high time that our ideas began to get crystallised about these things; hitherto there has been a great difference of opinion regarding them, and Mr. Field's contribution to the literature of the subject will, I hope, go far to enable us to arrive at some definite conclusions. I do not think that engineers realise, even yet, that three-phase distribution with a neutral conductor does for the alternating current precisely what the three-wire system did for the continuous current as regards the amount of copper to be used in the distribution. It does no more and no less than this. To be sure, as Mr. Field points out, it is possible to adopt a three-wire system for single-phase alternating currents, and in fact this has frequently been done; but when, with about the same expenditure on mains, one can, with a three-phase system, get all the advantages which are to be derived from the use of polyphase currents, it is difficult to conceive how any one would adopt the older system of single-phase, even with a three-wire system. Of course here we are heavily handicapped by the existence of old single-phase stations. These are being changed over gradually to a lower frequency, and at the same time the polyphase system is being introduced. Two phases are adopted because it is easier, having regard to the existing system of mains, to effect the change for two phases than for three. But I think it is safe to assert that the last single-phase station has been erected in Great Britain some time since. There will be no more of them. The new stations, provided they are not influenced by already existing conditions, will either generate polyphase currents of three phases, or simple continuous currents. Mr. Esson

Professor SILVANUS THOMPSON: We are much indebted to Mr. Field for the very valuable tabulation of facts that he has given us, Professor Thompson.

Professor Thompson.

and for the comparative outlook between the systems that he has set before us in this paper. But I disagree as to the suggestion which Mr. Esson has just made that it is now time that we crystallise our ideas. I hope we shall be very far from having our ideas crystallised on any one system or on any one set of facts. Indeed, I think that Mr. Field's paper will rather tell in the other direction. It has been so difficult to make headway in this country against the prejudice in favour of the continuous-current system, that perhaps some of us have seemed to be prejudiced on the other hand in favour of three-phase work. I hope I should be the last to crystallise into a prejudice of that kind. For there are unquestionably cases where there is something to be said for two-phase and for single-phase, and particularly in such cases as those last referred to by Mr. Esson, where you are met with the problem of changing over from a single-phase high-frequency system to something more modern. I do not think the right thing is simply to turn it out and put in a three-phase system straight off. I think there are intermediate courses which may be adopted. And one sees what can be done in various directions. For example, the Metropolitan Company, which had a single-phase alternating circuit over a very large area, is changing its system; but is not doing it by simply turning out the old station and putting in three-phase. Its engineers have begun in a very ingenious, and at the same time simple, manner—namely by putting in a two-phase plant at their generating station, and at first operating one only of the phases. Of course, you cannot make the large machines do such full duty under those circumstances; in some cases only half their coils are being used, but then, as you proceed with the work of changing over, you are gradually able to put section after section of the system on to the second phase of the distribution. There are, of course, other ways in which the same problem may be attacked, and not the least difficult part in the whole thing is the circumstance that the transformers that are suitable for the high-frequency system that has been in vogue are not suitable at any rate for the same frequency, or for a lower frequency, and ought indeed to be abandoned for such a purpose.

I was interested in finding Mr. Field going into detail over a plan which many years ago I suggested of avoiding the trouble of regulating all three phases at once in a mixed system of lighting and power—namely that of putting the light on to one phase only and regulating that, and letting the other two phases take care of themselves. There is another plan that I suggested at the same time, which Mr. Field does not mention, and that is, putting the lighting on to two of the phases and regulating these two, while letting the third take care of itself. One may put it diagrammatically thus: You put your lighting on to two legs of the letter V, and allow the angle between the two legs to take care of itself. The motors, when they are put on to the circuit, will of course employ all three phases, and every motor and every transformer that is put across the three mains helps to equalise the output, and aids in the regulation of the three phases.

I am glad also that Mr. Field points out that modern improvements in single-phase work have certainly made it possible to contemplate,

Professor Thompson.

in some cases at any rate, a return to the use of single-phase. We have not here, I am sorry to note, the presence of Mr. Ferranti, who has been the apostle of single-phase work. In spite of all that has been done in polyphase work during the last ten years, I know that Mr. Ferranti maintains unchanged his old opinion that the time will come when all these complications of two, of three, of four, and of six phases will be abolished, and that we shall all come back to using nothing but an alternating single-phase current. Well, I do not agree with him as a matter of fact, because I think there is a great deal to be said in favour of the three-phase and in some cases of the two-phase system; but still there is that possibility, and so we ought to keep our minds alive to it. The complications on the switchboard and other parts of three-phase work are supposed to be very dreadful. Only those who have worked with them practically, I suppose, know how very simple they may be made in a well-organised system. The difficulties of three-phase work from that point of view are much more imaginary than real. It would indeed be a pity if any discussion that took place here led to the idea that there was any unnecessary complication in three-phase work.

Mr. Rhodes.

Mr. W. G. Rhodes: I think that Mr. Field's paper is of the utmost interest, since it brings before an International meeting of engineers a question which is of vital importance at the present time.

There is one point in the paper which has not hitherto been noticed, and I wish to make a few remarks in order to excite discussion upon it. The question is—Which is the best system to adopt, the stationary transformer and converter, the synchronous motor-generator, or the asynchronous motor-generator? Some consider the combination of stationary transformer and converter the best because its efficiency is necessarily higher than that of the other two, since, in the transformer, there are no friction losses, and in the converter—except in single phase—the copper losses are less than those of a single machine, either generator or motor. The asynchronous motor-genérator is the worst system of the three for the reason that the power factor of the asynchronous motor necessitates a larger plant at the generation station than would otherwise be required.

From a theoretical standpoint I have already stated that the combination of stationary transformer and rotary converter is to be preferred. It is for those who have had extensive experience to say which is the better system of the two, the combination of stationary transformer and rotary converter or the synchronous motor-generator.

I shall be extremely glad to hear what our Continental and American friends may have to say on the subject. It is a question which appeals to us here, because there are cases now under consideration where in light railways of fairly long distance the transmission of power by continuous currents would be too costly.

Any additional information regarding this matter will be of great advantage to us all, and I hope that, having drawn attention to it, somebody else will supplement my remarks.

Herr Bláthy.

Herr O. T. Bláthy (*Budapest*): I wish to make some remarks on the last question which has been raised—Whether we should use rotary

Herr Bláthy. converters, synchronous motor-generators, or induction motors and continuous-current generators? It entirely depends upon the conditions which have to be satisfied. If accumulators are to be used in parallel with the continuous-current dynamos, generally, it will be found advantageous to use motor-generators, because the loading of the accumulators with a higher tension than the standard pressure at which they are used is somewhat more difficult with a rotary converter. In all cases where no accumulators are used, I think that the rotary converter and static transformer will have the advantage as well in the first cost as in the efficiency and in the capacity to carry over-loads. But the most suitable system to run tramways or railways from a central station is, in my mind, except in some very exceptional circumstances, to drive motors on railways or tramways direct with polyphase currents. There is absolutely no difficulty with the regulation, and there is no unnecessary loss; and I can prove and show that even with the very short runs which occur in municipal railways, or even where the stops are every few hundred yards, the economy of the polyphase system of running tramways is at least equal to the continuous-current system, whether the continuous currents are generated direct at the station or not. Very great progress in this respect has been made in the last few months, as is open to proof on the railway which we have built and are about to run in Italy, and I hope that many members of this Congress will have an early opportunity of seeing that railway. I may tell you that it will be open for public service within six weeks. That is a railway, about 67 miles long, which has up to date been worked by steam. It has a running speed of about 40 miles an hour. It is distinct from all other electric railways which have, so far, been built, because all other electric railways have been rather of the class of tramways and light railways. It is the first line of railway for a long distance which will be actuated by polyphase current.

The President. The PRESIDENT: Does that apply to the working of the whole traffic?

Herr Bláthy. Herr BLÁTHY: The whole traffic, yes. The passenger traffic will be run at 40 miles an hour, and the goods traffic at 20 miles an hour. The experiments are going on now; and I may speak of the economy of supply from the central station. The amount of energy per ton per mile from the central station is not more than is necessary for doing the same work with continuous current.

The President. The PRESIDENT: Is there any limitation with respect to the load of the trains?

Herr Bláthy. Herr BLÁTHY: No: there is no limitation.

The President. The PRESIDENT: You take the trains as they are worked by the steam locomotive?

Herr Bláthy. Herr BLÁTHY: At least as much. The electric locomotive of the same weight will draw at least the same weight as the steam locomotive, and generally more, as with the electric locomotive the whole weight can be used for adhesive purposes. There is another circumstance on which sufficient stress has perhaps not been laid. In every steam locomotive used the torque on the driving-wheel is a very variable one: it varies as between 2 and 3. Now its adhesive weight

Herr Bláthy.

must be sufficient to take the maximum. In every electric locomotive the torque is absolutely uniform, and the total adhesive weight is available for utilising the work of the motors. The electric locomotive will be sufficient for at least 30 or 40 per cent. more motive power than would a steam locomotive of equal adhesive weight.

Another very important thing that applies to every electric railway is this—generally you can say that roughly the weight of the electric locomotive to do the same amount of work as a steam locomotive will be about the same—rather less: but you are spared the whole weight of the tender; which, on the average, is 30 tons, *i.e.*, about 10 per cent. of the total weight of the railway train. So that, simply by introducing electric- instead of steam-traction, you have an economy of 10 per cent. of the weight you have to draw; or you can put 10 per cent. more useful weight on your trains than you can with a steam locomotive. If you work that out for the railways of the United Kingdom you will find that you would gain I do not know how many more millions of pounds of yearly income out of the increased useful weight you can carry on your railways with the same amount of work done, if the electric locomotive were used instead of the steam locomotive.

There is another question which I should like to touch upon—and that is the question of frequency. It is generally considered and accepted that the standard frequency is now 50. That is a thing which I contest. I say the standard of frequency—I do not state more than a general proposition—is very steadily going down to 42, and the larger number of new large stations which have been erected on the Continent have been erected with a frequency of 42. Forty-two is about the lowest frequency which can be successfully used for arc lights. That is the reason why it was accepted more than twenty years ago by my own firm (Ganz & Co.), and has never been departed from. For incandescent lighting we have also found the same thing as Professor Carhart. We have found that incandescent lights can be very well worked with about 22 periods; but there is a method of using lower periodicities for incandescent lights. If you put three filaments in a lamp, or (and it is the same thing) if you put three lamps close to one another, you can use any frequency just as low as you like, even with ten cycles, and you get an absolutely steady light as the sum of the energy transmitted by the three-phase circuit is constant. The energy-flow is a uniform one with the three-phase system; and that is the reason why the three-phase system is so good. In the single-phase system the flow of energy is constantly varying between a maximum and zero. In the two-phase it varies between 7 and 10, but in the three-phase system, supposing it is uniformly loaded, the energy-flow is constant, and it is evident that the most economical system, from a philosophical point of view, must be the one in which that is the case; and that is one of the reasons for the superiority of the continuous current with its uniform flow of energy over the single-phase alternating system. This great advantage is shared by the three-phase, but not by the two- or single-phase systems.

Then something has been said about the transforming of existing single-phase stations into polyphase stations. That is a change which

Bláthy. we effected in two big stations several years ago. A generating station, which had been a single-phase station for the previous ten years, was transformed into a two-phase station three or four years ago. There is a reason which compels one to do that. You cannot put three-phase currents in an existing system of single-phase mains if they are concentric, as most of the existing single-phase mains are. There are two conductors—one a core, the other a tube round it. You cannot use three of these cables in a three-phase system, as the effects of the capacity of the cables are so very peculiar. I cannot express it shortly otherwise than by saying that the potential difference between the cables and the earth does not know where to go to. That prohibits absolutely the use of three single-phase concentric conductors for three-phase work, and you have not any choice but to make two distinct two-phase circuits, and that answers very well, and makes it very easy, as Professor Thompson has explained, to go from single-phase to two-phase. But if a new plant has to be put up, I may confidently say that no Continental maker would think of putting in a single- or a two-phase plant: he would only put in a three-phase plant.

The President. The PRESIDENT: Can you tell us the average distance, or the maximum and minimum distances, of the stations on this railway?

Herr Bláthy. Herr BLÁTHY: I cannot tell you the number of stations, but they are about three miles apart.

Mr. Stoney. Mr. GERALD STONEY: In Note II. to the paper, there is a mention of the Frankfurt station, and it seems very significant that in this station, which has long been looked upon as the stronghold of single-phase, a three-phase Turbo-Alternator is being installed, which is to give 3,000 kilowatts three-phase, or 2,600 single-phase. It is, I believe, to be worked as described in the paper—that is, the single-phase work is to be done off one phase, and the other left to take care of itself.

There is another point which has not been touched upon in the paper, that is the advantage of sychronous motors in reducing the lag due to induction motors by exciting them so as to act as condensers. At Frankfurt I believe the lag used to be 0·7 to 0·8, but by use of synchronous motors driving the continuous-current tramway generators this has been reduced to about 0·95, which has meant a much larger output for the alternators. The note says, "The lamps and motors are all connected to the same machines, feeders, etc. The motor-generators for traction purposes are usually operated separately, *i.e.*, from separate machines and feeders." I was, however, given to understand that they were all run together so that by over-exciting the motor-generators the lag might be decreased.

Mr. Geipel. Mr. W. GEIPEL: I would like to make one remark, before the discussion closes, with reference to the variation of the lamps when put on one phase or on the three phases. I made an experiment a year or two ago on a rather large installation of three-phase plant where we put the lamps on the three phases, and we made a test by turning the whole of the lamps off two of the phases, leaving the other phase alone loaded, so far as concerns the lamps; but the motors were running, of course, as before. When the whole of the lamps on the two phases were turned off it only made a difference of 2 per cent. in the voltage of the

other lamps. Of course that is a condition which in lighting you would never get: you would always arrange to burn your lamps considerably better than that. Mr. Geipel.

With regard to the complications which Professor Thompson spoke of as being quite imaginary in the case of three-phase switch-boards, I can quite confirm what he says; and I will point out this advantage—that you are dealing with three smaller switches instead of with two larger ones, and the manufacture of a three-phase switch-board is, in my experience, really somewhat easier than that of a single-phase or continuous-current switch-board for that very reason.

Then I would also like to point out that, with a three-phase lighting system, you are enabled to use lower voltage lamps, while still obtaining the economy of the higher voltage for motors, which I consider is a great point in its favour. And, further than that, in comparing the advantage of single-phase, two-phase, and three-phase systems, I think we ought to take into consideration the cost of the generators. The cost of a three-phase generator for the same output is enormously less than that of a single-phase generator.

Mr. F. BROADBENT: As Mr. Field has touched on distributing by alternating currents, I should like to ask, for information, if he has the comparative costs of distributors for alternating and continuous currents. It would appear to me that, under the existing Board of Trade regulations, the declared pressure on an alternating system must be considerably lower than is allowed for continuous currents; that is, the maximum impressed voltage of the alternating system must be the same as the steady voltage on the continuous-current system. This would involve larger distributors in the one case than in the other, and although it is perhaps not quite relevant to the subject under discussion, I would like to hear if Mr. Field has considered the subject from this point of view. Mr. Broadbent.

Mr. M. B. FIELD (in reply): Messrs. Kolben and Bláthy spoke at some length on the subject of three-phase motors for traction work. The only phase of this subject which can be considered as falling within the scope of this paper is that of three-phase motors for tramways. This I have briefly touched upon in the paper and have given my views. I have purposely not touched upon heavy-traction systems, for if such be operated with three-phase motors, in the future the motors will not be fed from "low-tension networks," but rather from high-tension lines. The voltage may, of course, be less than that used for transmission purposes from the generating station, but still the line or network from which such locomotives or automobile cars will be supplied with power will be a very different sort of network from that referred to in the paper throughout as a "low-tension network." I would like, however, to express my own indebtedness to the above-named gentlemen for the information they have volunteered on the subject of heavy railway work. Coming as it does from such authorities on the subject, I am sure every one here will appreciate its value. Mr. Field.

The next point raised was, I believe, in connection with Note IV. at the end of the paper; I should have mentioned that this table was reproduced in order to show the balancing effect of three-phase motors

Mr Field. when connected to an unequally loaded three-phase circuit. It was not intended to show the variation of voltage which might be expected from a three-phase generator when unevenly loaded with power and light. The generator in question was of the inductor type with a fairly large drop, and was therefore particularly well suited for the purpose of showing the balancing effect on the three phases of a three-phase induction motor when only one is loaded on lamps.

Professor Carhart referred to the extensive use of the three-phase system in America, and stated that he thought two-phases were never adopted there. I think that, except in cases such as Dr. Thompson and Mr. Esson have mentioned, the two-phase system has no advantage of any moment over the three-phase system; but it is also true that in *many* systems the three-phase would be no more advantageous than the two-phase.

Where, however, Board of Trade regulations are in force, these considerations may be affected as explained in the paper. I was very glad to hear Dr. Thompson refer to the absence of complications in connection with modern three-phase plants, and I think that when you have visited the Pinkston generating station and one of our tramway sub-stations you will be prepared to agree that the whole arrangements are as simple as with any good up-to-date single-phase system of like nature.

I do not fully agree with the method Dr. Thompson referred to of putting the lighting on two legs of a three-phase system, and letting the "angle of the V take care of itself." It might be wanted to increase the voltage represented by the length of one side of the V *only*, without affecting the other side, but this would not be feasible.

I quite agree with Herr Bláthy's view *re* the desirability of motor generators in preference to rotaries where accumulators are to be charged. If rotaries be used, probably regulating boosters direct coupled on the D.C. side will be found to give the most practicable combination. I do not understand fully what Herr Bláthy means by saying the energy flow in a two-phase system varies between 7 and 10. I have always considered that the power in a two-phase circuit is at every instant theoretically as constant as in a three-phase system provided the load be balanced in each case.

Take the two-phase case. In phase A we have—

$$\text{Volts} = \text{V} \sin k\,t,$$
$$\text{Current} = \text{C} \sin (k\,t - \phi).$$

In phase B we have—

$$\text{Volts} = \text{V} \sin (k\,t + 90^\circ),$$
$$\text{Current} = \text{C} \sin (k\,t + 90^\circ - \phi).$$

The total power is then—

$$\text{V C} \left(\sin k\,t.\ \ \text{Sin}\,(k\,t - \phi) + \sin (k\,t + 90^\circ).\ \ \text{Sin}\,(k\,t + 90^\circ - \phi)\right),$$

which, if expanded, is found to be a constant quantity independent of t.

Similarly, the torque of a perfect two-phase induction motor is theoretically uniform, just as is that of a three-phase induction motor. I admit, however, that practically these ideal conditions can be more nearly realised with a three-phase system than with a two-phase system. I do not explain to myself the superiority of the three-phase system in the way Herr Bláthy has indicated, but rather in the way I have given in my paper at the commencement of the discussion on the cable system. Mr. Field.

Mr. Stoney referred to the use of synchronous motors for reducing the lag on an alternating system. I do not think as a rule it pays to effect this result in this way. If the motors are capable of sufficient over-excitation, it means they are considerably stronger motors than would be actually required for the work they have to do. Unless these motors run at exceptionally high speeds, it would be found in most cases better to put this extra money into the generators and prime movers, and make them such that the extra output can be obtained therefrom without resorting to over-excitation of the motors.

Of course, over-exciting the motors has the advantage of improving the transmission efficiency, which under certain circumstances, and particularly when dealing with long lines, may render the adoption of the principle advantageous.

I refer in the paper to voltage-curves taken from direct-current 'bus-bars. These show that without any special regulation in the power-station the voltage on the direct-current 'bus-bars in the sub-stations varies up and down by about 2 per cent., with occasionally a total maximum of 4 per cent. variation. If it were a lighting station, I have no doubt that by paying close attention to the load at Pinkston considerably closer regulation in the sub-station could be obtained.

Mr. Stoney further referred to my remarks on the Frankfurt station and seems to consider that my information is incorrect. As, however, my data came straight from Frankfurt, I am unable to understand where the discrepancy comes in.

Lastly, in answer to Mr. Broadbent, I would add that I have not the figures necessary for the comparison of the price of cables for direct-current and alternating-current distributing systems. They are easily obtained from any good cable-maker. I have indicated, however, that one cannot lay any standard alternating system of distributing mains cheaper than the corresponding three-wire continuous-current system.

The PRESIDENT: Mr. Field's paper, as I anticipated, has elicited an excellent discussion. We have not only been favoured with the views of a number of eminent men of our own country, but of those representing other countries, men who have been engaged in carrying out important works in those countries. We are all greatly indebted to Mr. Field for having given us the opportunity of hearing those views, and I am sure you will gladly accord him a very hearty vote of thanks for his paper. The President

The vote of thanks was carried by acclamation.

The PRESIDENT: It is proposed to take the discussion on the two remaining papers together, and I call upon Mr. Hobart to read first an abstract of his paper.

MODERN COMMUTATING DYNAMO MACHINERY, WITH SPECIAL REFERENCE TO THE COMMUTATING LIMITS.

By H. M. HOBART, M.I.E.E.

Of recent years the improvements in continuous-current dynamos that have received the greatest attention have generally related to some strictly radical departure from the straightforward type, such as to pole-face windings, to divided poles, to reversing lugs, and to many other interesting and often fairly effective devices.

Although none of these have, as yet, become extensively introduced, it would be by no means correct to infer that for that reason they are impracticable or in any way inferior to the more usual types. One or other of them may eventually, aided by especially opportune circumstances, be brought—or forced—into extensive use, and then, if actually an improvement, will become incorporated in the generally accepted type. The element of chance in matters of this sort has of late years made a deep impression upon the writer. Having taken for a very long time an especial interest in dynamo design, it has nevertheless not been practicable, for long intervals together, for him to give it his undivided attention, and it has been interesting, although rather discouraging, to find such deep-rooted conservatism in this branch of an industry generally believed to be characterised throughout by abnormally rapid development. It has never to the writer seemed necessary to resort to the special features referred to above, since there has always been, and is still, ample room for improvement in the ordinary type; sufficient room, he believes, very greatly to modify our views as to what should constitute a first-class dynamo.

The writer has been led to these reflections, as already intimated, by the realisation that his ideal of a system of dynamo machines, or rather that approach to it which it would at first sight seem so extremely simple and rational to carry out, and so highly desirable, as well from the broad commercial as from the technical standpoint, remains year

after year apparently almost as far as ever from accomplishment. In individual machines one may, by the greatest persistency, manage to arrange to get one or the other feature introduced, and occasionally such features find favour and become more or less widely adopted; much more generally, whatever their merits, they are laid aside, frequently from no deeper motive than from a consideration of the commercial expediency at the moment, modified by a conservative tendency to retain old types as long as practicable. It is proposed in this paper to set forth certain views regarding the continuous-current dynamo electric machine. No features of very especial novelty are claimed. The designs described do not depart radically from machines at present on the market; but to construct a consistent system, embracing machines of all the various ratings required by a single manufacturing firm for successfully entering the field, is another matter altogether from designing a single, excellent dynamo, and it is from this broad point of view that it is proposed to discuss the subject.

The first point to be emphasised is the predominating influence which the normal voltage of a machine should have upon its proportions. Contrary to the ruling tendencies there should, in many features, be greater differences between a 500-volt and a 100-volt machine for the same output and speed than between two machines of the same voltage and very different outputs. Of course this has been recognised for a long time, and one very often sees instances where the design is correct, considered from the standpoint of the rated voltage. But concerns standardising lines of comparatively small machines of many listed ratings, from very small sizes up to 100 k.w. or even higher, are reluctant to admit the economy of fully observing this principle. So comparatively recently as eight or ten years ago there were but very few exceptions to the custom of using, for a given output and speed, the same magnetic circuit, the same armature spider and commutator shell, and often even the same armature coils and the same commutator segments, for 500, 250, and 125 volts. In those days great confidence was still felt in many quarters in the possibilities of double, triple, etc., windings, both two-circuit and multiple circuit, in cross connections, in interpolated segments, and in other devices which work

out very satisfactorily in the calculating and draughting offices, and especially in the shop. The writer's own opinion is that most of such windings are distinctly inferior. Firms have been heard of who assert that the results in the testing-room and after installation are in every respect beyond criticism. It is nevertheless not at all exceptional to learn, at a later date, of their having discarded these methods. The writer most certainly believes that the simplest windings are in the end by far the most satisfactory, and that by making suitable use of them they suffice for all ordinary requirements. But in those days, with all these special windings and connections to choose from, nothing was easier than to arrange that, for instance, the 4-pole dynamo for 500 volts should have a two-circuit single winding, the 250-volt machine should have the same winding connected as a four-circuit single winding, and for 125 volts the dynamo could be connected up into a four-circuit double winding.

As to the commutator, there then existed various rules with which it was known to be very desirable to comply, but these offered inconveniences, and it was sometimes decided to use the same commutator for all three voltages, carbon brushes, then more of a novelty, for 500 volts, and copper brushes for 250 and 125 volts. Just why it should have been expected that copper brushes would be much more practicable for these lower voltages it is not now so easy to imagine, but it must be remembered that the standard of excellence was at that date altogether different from the standard of to-day. A commutator which, when running with load, could be described as anything less than very hot was then decidedly the exception; and as to sparkless collection of the current, machines in those days termed excellent would to-day never leave the manufacturer's shop. The practicability of shifting the brushes in proportion to load was, in the case of generators, only just beginning to be questioned, and large machines in which overloads could be thrown off with impunity were not easily to be found.

There is a remarkable persistency in old types, and even in the latest product of the foremost manufacturers of the present day one has no difficulty in finding numerous traces of these ideas. One rarely encounters low voltage machines

in which the commutators are anywhere nearly so liberally proportioned for their requirements, from the heating standpoint, as in machines for high voltage. On the other hand, the machines for high voltage have not by far so liberal a factor of safety as regards insulation as have those of lower voltage; and the former have, as a rule, disproportionately greater losses in the armature windings and core and in the field spools, and often are rated at a higher speed to avoid the difficulty of having a proportionately greater number of armature conductors with the attendant increase in space due to the greater subdivision and to the higher insulation requirements. It would appear to be quite correct to permit these tendencies to a certain extent, as a concession to the expenses of manufacture, but certainly very much more regard should be shown than is now the case to the designing of machines with reference not only to the kilowatts capacity, but to the voltage and ampereage as well.

There is, however, one point possessed in common by machines of greatly different voltages but for the same output and speed, namely, the mechanical energy to be transformed into electrical energy, or *vice versâ*. Hence it would seem natural and desirable that base, stands, bearings and shaft should be identical for all voltages. By the methods now to be described this may readily and, the writer believes, most *economically* be obtained.

Numerous tests have satisfied the writer that the magnitude of the reactance voltage per commutator segment is of the very first importance in determining the performance of the machine from the commutating standpoint. It is of far more importance to have low reactance voltage per segment than to have low armature strength, as expressed in ampere-turns per armature pole. In fact it is nowadays the writer's practice—speaking broadly—to make the armature strength as high as practicable so long as this is consistent (and it generally is) with low cost of effective material, with practicable proportions of field, armature, and commutator, and, above all, with obtaining minimum reactance voltage. The writer would be inclined, from this rough, practical standpoint, to estimate the harmful influence of armature strength upon commutation as proportional to, at most, the square root of the armature ampere-turns per pole.

Next should be pointed out, that the higher the voltage, the more is the least practicable thickness of the commutator segment apt to be the limit in determining the number of segments per pole-piece, and hence the number of armature-turns or coils per pole-piece. This consideration, together with the greater proportion of the available space on the armature periphery, which should, in the 500-volt machine, be devoted to insulation, and the greater cost of the labour associated with the windings and insulation, make it much less practicable to have so high armature strength in a high voltage as in a low voltage machine.

But on the other hand, in the high voltage machine the commutator's duty (because of the low amperage) is light. It requires to have devoted to it but a small portion of the distance between bearings, thus leaving ample room for employing, for high voltages, a weak armature (as expressed in ampere-turns per armature pole), but one occupying, owing to the consequently greater necessary cross-section of its magnetic circuit, a large proportion of the total distance available between bearings.

A still more influential consideration tending toward a widening of the armature proper in the high voltage dynamo, is that the centrifugal force at the commutator periphery limiting the commutator circumference, and the thinness of the segment limiting the total number of segments, one should, in order to obtain a sufficiently large number of segments to ensure a low reactance voltage per segment, employ fewer poles in the high voltage dynamo than in that for lower voltage. And that is precisely what one wants for other important reasons—namely from considerations relating to the design of the commutator—since the high voltage (low amperage) commutator comes short enough even with few poles, but it is only by means of comparatively many poles that we secure—with low voltage (high amperage)—machines of desirably low amperage value of the current per set of brushes, to permit of a reasonably short commutator.

Now as to the most desirable commutator diameter, the writer believes that the limiting peripheral speed should be set very high. Especially on the large diameters occurring in direct-connected units there should be no difficulty, since for a given peripheral speed the centrifugal effects

are inversely as the diameter. In any case, it is purely a question of using a sufficiently liberal amount of material in the mechanical construction of the foundations, base, shaft, and commutator to ensure a perfectly true, continuous commutator surface, absolutely free from any vibration whatsoever. For a high voltage machine, a large diameter enables the reactance voltage to be maintained low in virtue of the large number of segments per pole thereby secured (the permissible minimum thickness of segments being the limit). For low voltage machines the necessary radiating surface for transmitting the high current is the limit, and the greater the diameter, the less need be its axial length. Hence, governed by these two considerations, it is fairly logical to choose the same diameter of commutator for all voltages for a machine of a given output and speed. It is furthermore very practicable also to employ for all voltages the same diameter of magnetic yoke, of bore and of armature laminations, the variations with the rated voltage being limited to width of magnetic circuit, of armature core and of segments, as well as to windings, to numbers of slots and segments, and to the number of poles. As at first stated, all essentially *mechanical* parts—base, stands, bearing and shaft, as well as distance between bearings—are entirely independent of the voltage, so that *absolutely* the same drawings, patterns, and castings are used for all voltages. Since, of the *variable* parts, magnetic frame, armature punchings, armature spider, commutator spider and brush-holder supporting ring, the diameters are the same for all voltages, it is practicable, by the exercise of care and ingenuity, to arrange to use the same drawings, and substantially the same patterns, the latter being arranged for special modifications for being extended and shortened for the different voltages. This is roughly indicated in the sketches of Fig. 1, in which, however, no claim is made to have worked out the plans for interchangeability in correct detail.[1] The sketches in the figure relate to a line of four machines by which it is proposed to illustrate the application of these principles.

[1] In the sketches the brush-holder supporting rings are different for the three voltages. This also could have been avoided either by special proportioning of the width of the magnet yoke, or by a special brush-gear supporting frame fixed directly on the base, this latter plan being often preferable on the score of the greater rigidity thereby secured.

Each model is worked out for three dynamo voltages, 115, 230, and 550. The number of poles, outputs, speeds, and voltages are set forth in Table I.

TABLE I.

Number of Poles for			Rated Output and Speed.	
115 V.	230 V.	550 V.	K.W.	R.P.M.
6	6	6	80	580
8	6	6	100	500
8	6	6	125	450
8	8	6	150	425

In Fig. 1, side and end elevations of the 100-k.w. model are given for each of the three voltages. In Table II. are set forth the leading dimensions and some other data for all the four machines of the series.

It is proposed next to give, in a series of Tables, some further particulars of the designs. (See pp. 178–183.)

Current Density in Armature Conductors.

The current density in the armature conductors ranges from 390[1] amperes per square centimetre in the 80-kilowatt machine, down to 360 amperes per square centimetre in that for 150 kilowatts.

Insulation and "Space Factor."

By space factor for the slot, is denoted the ratio of the total cross-section of copper in the slot, to the area of the slot, *i.e.*, to the product of its width by its depth. In these machines it is very uniformly as set forth in Table VI., wherein are also given the corresponding guaranteed insulation tests and, for the insulating materials employed, the required total thickness of slot insulation from copper to iron.

[1] Recent experience has shown even these current densities to be rather too conservative in view of the ventilation provided for in these designs.

It will be seen that the 115-volt armatures and commutators[1] are run as high toward the heating limit as practicable, in order to keep the machines down to the same overall dimensions as for the higher voltages.

The commutators of the 550-volt machines are cooler than necessary, the limit, in their case, being the permissible current density at the brush contacts, this being, for all voltages, taken at 5 amperes per square centimetre.

A rather interesting result in connection with these designs, is that relating to the cost of "net effective material" per kilowatt.

For the entire range of capacities (80 k.w. to 150 k.w.) and voltages (115 volts to 550 volts) this varies but little from the average value of 16·3 shillings per kilowatt, being (on account of the corresponding rated speed) independent of the rated output, and (on account of the basis of the design) practically independent of the voltage, the variations above and below the mean value of 16·3 shillings per kilowatt being entirely irregular, and rarely over 7 per cent. But the total factory cost will be less per kilowatt the greater the capacity, since, in large capacities, the "net effective material" constitutes a higher percentage of the total factory cost.

The basis on which the cost of "effective material" was calculated, is :—

	Pence per Kilogramme.
Armature copper	24
Field "	24
Commutator segments	24
Magnet yoke and cores (cast steel and wrought iron)	4·5
Pole faces (cast iron)	3·0
Armature laminations (sheet steel) ...	3·6

Although for the prevailing prices it was more economical to employ cast steel for the magnet yoke, the writer would prefer cast iron, as he attributes great importance to stability. In some countries the relative prices for these two materials would also make it more economical to use cast iron for the magnet yoke.

[1] For well-ventilated high-speed armatures and for sparkless commutators, one may safely estimate the temperature rise, by thermometer, at not over 0·8° Cent. per watt per sq. dm. of peripheral surface.

TABLE

Number of Poles.	Kilowatts Output.	Revolutions per Minute.	Voltage.	A	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.
6	80	580	115	1366	1650	1300	740	610	1325	340	660	620	330	215	1350
6	80	580	230	1366	1650	1300	740	610	1325	390	610	620	430	250	1350
6	80	580	550	1366	1650	1300	740	610	1325	420	580	620	500	400	1350
8	100	500	115	1585	1900	1500	900	710	1450	370	730	710	395	190	1470
6	100	500	230	1585	1900	1500	900	710	1450	420	680	710	470	260	1470
6	100	500	550	1585	1900	1500	900	710	1450	460	640	710	550	420	1470
8	125	450	115	1813	2210	1740	1070	790	1650	395	875	720	370	200	1660
6	125	450	230	1813	2210	1740	1070	790	1650	445	825	720	460	300	1660
6	125	450	550	1813	2210	1740	1070	790	1650	485	785	720	550	435	1660
8	150	425	115	2114	2470	2030	1200	840	1735	390	940	770	350	275	1740
8	150	425	230	2114	2470	2030	1200	840	1735	450	880	770	475	300	1740
6	150	425	550	2114	2470	2030	1200	840	1735	500	830	770	580	330	1740

II.

Length of Laminations between Flanges.	Number of Ventilating Ducts.	Width of each Ventilating Duct.	Effective Length of Armature Laminations.	Diameter of Magnet Core.	Radial Length of Magnet Core.	Number of Armature Slots.	Width of Slot.	Depth of Slot.	Number of Commutator Segments.	Thickness of Segments at Surface (excl. Insulation).	Thickness of Segment from Commutator Connection to outer end of Commutator	Armature Conductors per Slot.	Height of Armature Conductor.	Width of Armature Conductor.
125	3	10	80	155	190	60	16·2	28·0	240	7·2	290	8	11·1	2·7
170	5	10	108	170	190	96	10·4	29·5	384	4·2	190	8	12	1·2
282	6	10	200	225	190	102	11·5	19·0	510	3	120	10	6·3	1
125	3	10	80	130	210	102	14·5	30·0	408	4·7	315	8	12·3	2·3
165	5	10	104	175	210	108	11·8	30·0	432	4·4	230	8	12	1·6
248	6	10	169	232	210	114	11·4	22·5	570	3·2	160	10	8	1
125	3	10	80	152	235	112	14·0	30·0	336	6·7	350	6	11·7	3·1
160	5	10	99	195	235	130	11·0	30·0	390	5·6	250	6	11·7	2·1
220	6	10	144	235	235	156	10·6	25·0	624	3·1	170	8	8·6	1·2
125	4	10	77	154	250	120	14·0	32·5	360	6·9	400	6	12·2	3·7
160	5	10	99	165	250	144	12·0	33·0	576	3·7	275	8	12·5	1·8
220	6	10	126	235	250	168	11·4	26·0	672	3·2	170	8	9	1·4

TABLE III.

Voltage.	Armature Ampere-Turns per Pole.			
	80 K.W.	100 K.W.	125 K.W.	150 K.W.
115	4640	5550	5700	7300
230	3710	5220	5880	5800
550	2050	2880	4000	5100

TABLE IV.

Voltage.	Reactance Voltage per Segment.			
	80 K.W.	100 K.W.	125 K.W.	150 K.W.
115	1·9	2·7	2·1	2·7
230	2·0	2·5	2·5	2·8
550	1·8	2·4	2·4	2·7

TABLE V.

Voltage.	Average Voltage per Commutator Segment.			
	80 K.W.	100 K.W.	125 K.W.	150 K.W.
115	2·9	2·3	2·7	2·6
230	3·6	3·2	3·5	3·2
550	6·5	5·8	5·3	4·9

TABLE VI.

INSULATION AND "SPACE FACTOR."

Voltage.	Guaranteed Insulation Test from Copper to Iron at 20° C. for One Minute.	Thickness of Insulation from Copper to Iron.	"Space Factor."
115	2500 R.M.S. Volts.	1·2 mm.	·53
230	3000 " "	1·3 mm.	·41
550	3500 " "	1·5 mm	·32

The mica insulation between commutator segments is ·76 millimetre thick.

TABLE VII.

Kilowatts. Rated Output.	Radial Depth of Gap (in mm.).	Peripheral Speed in Metres per Sec.		Centrifugal Force at the Periphery in Kilogrammes per Kilogramme. *	
		Armature.	Commutator.	Armature.	Commutator.
80	6·0	22·5	18·5	139	115
100	6·5	23·5	18·6	126	100
125	6·5	25·5	18·6	122	90
150	7·0	26·8	18·7	121	85

* If D = diameter in centimetres
n = revolutions per minute ;
Centrifugal force = 0·00000559 Dn^2 kilogrammes per kilogramme.

TABLE VIII.

Armature Losses in Kilowatts at 60° Centigrade.

Voltage.	80 K.W.			100 K.W.			125 K.W.			150 K.W.		
	Core.	C^2R	Total.	Core.	C^2R	Total.	Core.	C^2R	Total.	Core.	C^2R	Total.
115	1·8	2·5	4·3	1·3	4·0	5·3	2·5	5·3	7·8	3·4	6·9	10·3
230	2·0	2·3	4·3	2·1	3·6	5·7	3·4	5·0	8·4	3·9	6·9	10·8
550	3·3	1·5	4·8	3·6	2·1	5·7	3·9	4·5	8·4	4·3	6·2	10·5

TABLE IX.

Commutator Losses in Kilowatts at 60° Centigrade.[1]

Voltage.	80 K.W.			100 K.W.			125 K.W.			150 K.W.		
	Friction.	C^2R	Total.	Friction.	C^2R	Total.	Friction.	C^2R	Total.	Friction.	C^2R	Total.
115	1·6	1·4	3·0	2·1	1·7	3·8	2·5	2·2	4·7	2·8	2·8	5·6
230	0·8	0·7	1·5	1·0	0·9	1·9	1·2	1·1	2.3	1·4	1·3	2·7
550	0·3	0·3	0·6	0·4	0·4	0·8	0·5	0·5	1·0	0·6	0·6	1·2

TABLE X.

Field Copper Losses at 60° Centigrade.

Voltage.	80 K.W.	100 K.W.	125 K.W.	150 K.W.
115	860	1140	1400	1650
230	840	1000	1350	1650
550	1030	1240	1450	1640

[1] The commutator losses are figured on a brush resistance of 0·2 ohms per square cm., a brush pressure of 0·1 kg. per square cm., and on a friction coefficient of 0·3.

TABLE XI.

Total Losses at 60° Centigrade in Kilowatts.

Voltage.	80 K.W.			100 K.W.			125 K.W.			150 K.W.		
	Const.	Var.	Total.	Const.	Var.	Total.	Const.	Var.	Total.	Const.	Var.	Total.
115	5·4	3·9	9·3	6·0	5·7	11.7	8·2	7·5	15·7	10·1	9·7	19·8
230	4·8	3·0	7·8	5·6	4·5	10·1	7·8	6·1	13·9	9·2	8·2	17·4
550	5·8	1·8	7·6	6·7	2·5	9·2	7·7	5·0	12·7	8·8	6·8	15·6

TABLE XII.

Commercial Efficiencies at 60° Centigrade.

Voltage.	80 K.W.			100 K.W.			125 K.W.			150 K.W.		
	F. L.	¾ L.	½ L.	F. L.	¾ L.	½ L.	F. L.	¾ L.	½ L.	F. L.	¾ L.	½ L.
115	89·5	88·7	86·3	89·5	89·0	87·1	89·0	88·0	86·0	88·5	87·7	85·6
230	91·1	90·2	87·7	90·7	90·2	88·1	90·0	89·2	87·0	89·5	89·0	87·0
550	91·3	89·8	86·5	91·5	90·2	87·2	90·8	89·8	87·5	90·5	89·7	87·6

TABLE XIII.

Thermal Constants for all Four Machines.

Watts per Square Decimetre Peripheral (Cylindrical) Radiating Surface at 60° Centigrade.

Voltage.	Armature.	Commutator.	Field Spools.
115	(About) 55	57	10
230	„ 50	40	10
550	„ 40	28	10

The writer believes that—while not remarkably low—the cost of 16·3 shillings, when figured on this basis, per kilowatt of "net effective material" is, for designs for these ratings, speeds and voltages, excellent for high-grade machines with liberal over-load capacity. The writer would have liked to give comparative figures of this sort for machines of various firms when based strictly on the same

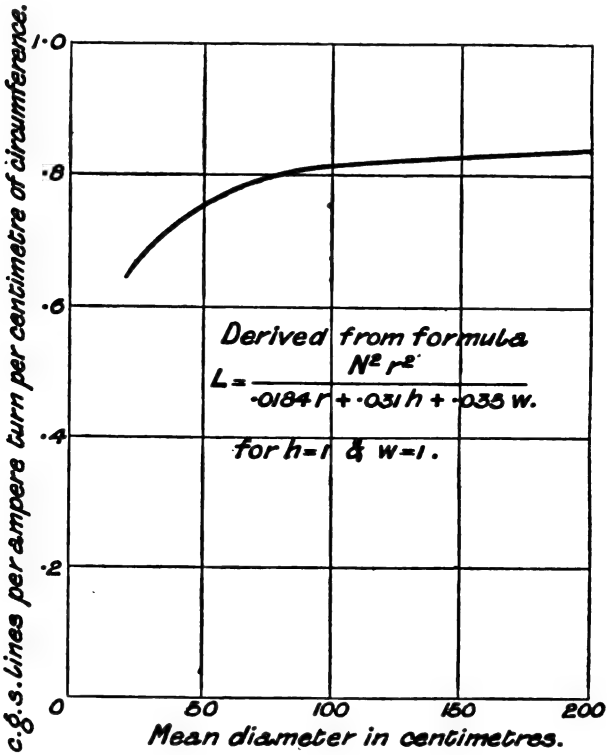

FIG. 2.

guarantees. It would be of great interest to know what others have accomplished in this respect.

From 200 k.w. upwards there has been, for the last two or three years, practically no demand for continuous-current machines of lest than 200 rated volts. Hence at present 115-volt machines for outputs above 200 k.w. may be regarded as special, and the principles set forth need, in these larger sizes, only be considered as applying to machines for 230 volts and 550 volts. It is, however, not unlikely that with

the increasing demand for electric energy for the various electro-chemical and electro-metallurgical processes, lower voltage continuous-current machines of large capacities will again be required. But in all probability the great variety of voltages employed would necessitate their generally being special machines.

Considerable emphasis has been laid upon the importance of low reactance voltage. This quantity not being

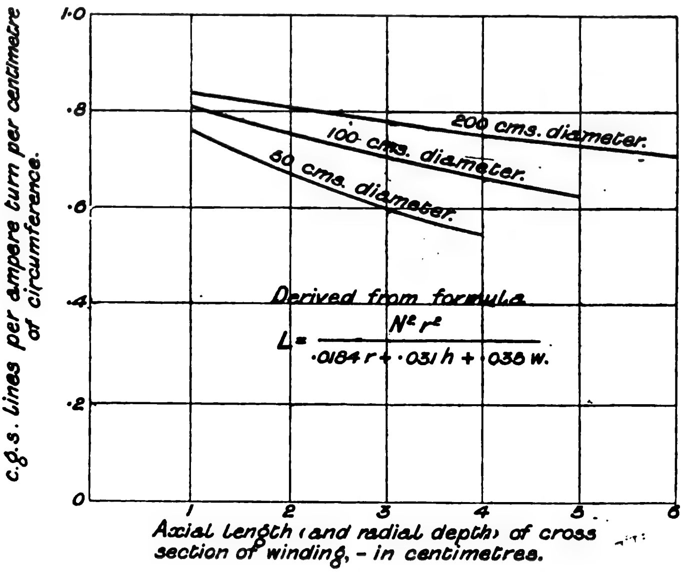

FIG. 3.

conveniently measurable under the precise conditions in which it affects the commutation, each designer estimates it on the basis of whichever method his experience has led him to consider least unreliable. The writer proposes to describe the method which he prefers for this purpose.

Professor Perry gives the following approximate formula for the inductance L in centimetres[1] of a cylindrical spool of N turns free in air, whose width w, mean radius r, and height of winding h (expressed in centimetres), are of such dimensions that $\frac{w}{r}$ and $\frac{h}{r}$ are very small :—

$$L = \frac{N^2 r^2}{\cdot 0184\, r + \cdot 031\, h + \cdot 035\, w}$$

[1] To reduce centimetres to henrys, multiply by 10^{-9}.

Solving this for a coil of a cross-section of one square centimetre for various diameters, we derive the curve given in Fig. 2.

The curves of Fig. 3 give the corresponding values for square cross-sections of coil for diameters of 50, 100, and 200 centimetres.

A few experiments have been made with a view to ascertaining how far the values given by these curves—in which the results are given in terms of the flux per centimetre of length of coil[1]—may, for rough practical purposes, be used for other than circular coils. Five coils were prepared, of the shapes and dimensions shown in Fig. 4.

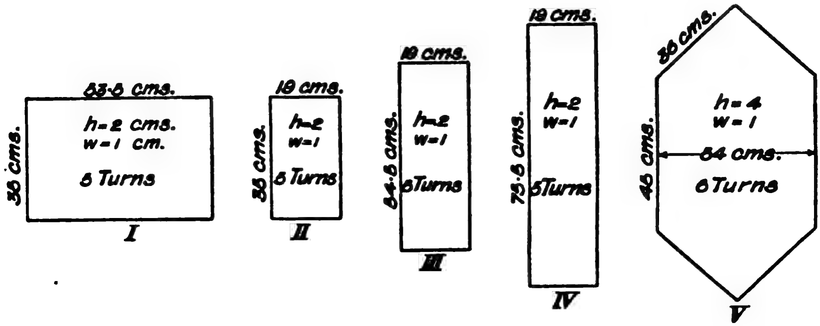

FIG. 4.

The inductance of these was measured on a 50-cycle circuit supplied from a uni-slot alternator. It was afterwards found in another set of inductance tests, that this alternator gave results 23 per cent. higher than when the circuit was supplied by an alternator giving a more ordinary wave-form. The particular machine giving the lower results with which comparison was made had three slots per pole. Besides the values observed on the circuit of the uni-slot machine, there are given in Table XIV., where the results of the tests are set forth, also a set of values corrected by 15 per cent. for the purpose of arriving at more representative results.

[1] A linkage of 10^{-1} c.g.s. lines corresponds to an inductance of 1 centimetre, or of 10^{-9} henrys.

TABLE XIV.

Coil.	Mean length per turn (cm.)	Diameter of circular coil of same periphery.	Value for circular coil from Fig 3.	Value observed in uni-slot alternator with abnormal wave shape.	15% lower value to correspond more nearly to average wave shapes.
I.	177	56	·73	1·0	·87
II.	105	33	·65	1·0	·87
III.	147	47	·70	1·1	·95
IV.	189	60	·75	1·2	1·05
V.	234	74	·70	1·2	1·05

This shows the experimental values, although higher, to be not altogether different from those which one obtains by this rather free use of the formula :—

$$L = \frac{N^2 r^2}{\cdot 0184 r + \cdot 031 h + \cdot 035 w}$$

Only the tests on these five coils were available, and, partly on account of the meagreness of these data, but more because the results thereby obtained correspond better with the final average results in practice, the writer has preferred to work from the basis of the formula, as arranged in the curves of Fig. 3. Furthermore, in this matter of the reactance voltage, it is the *relative* values for different machines which possess the chief importance. Justification for this course will be more evident later.

The customary shape of the coil of a continuous-current dynamo is as follows :—

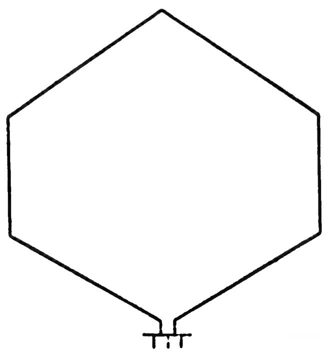

FIG. 5.

and the portions lying outside of the slots will be treated as having values for the inductance per centimetre of length of some such amounts as are given by the curves of Fig. 3.

It must, however, be observed that several coils are simultaneously short-circuited under the brushes, and hence the turns making up the short-circuited group are considerably spread out. As three to five segments are generally at the same time under the brush, two to four coils per brush come into consideration. Hence the complete coil on which we must reckon is much as shown in Fig. 6,

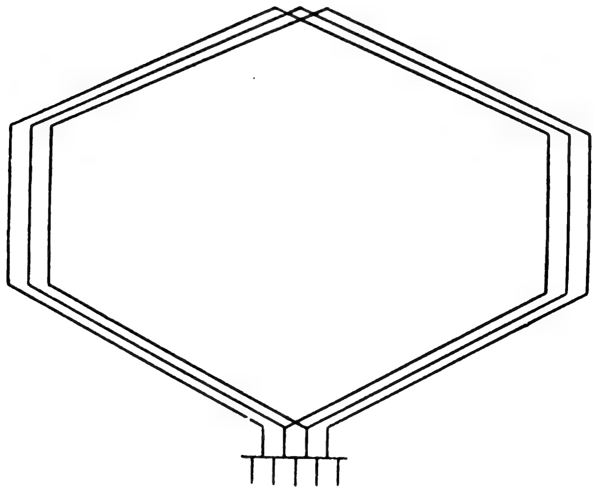

FIG. 6.

i.e., rather spread out. A representative cross-section may, for a rough basis, be taken as having (considering the equivalent circular loop) an axial length of one centimetre and a radial depth of two centimetres, and we might take from 40 to 80 cms. as the customary range of diameters. It will be seen from the curve that, on this basis, there will be about ·7 c.g.s. lines per ampere-turn per centimetre of length for the free part of the coil.

For the portion lying embedded in the slots, various observations lead to a representative value of about four lines per centimetre of effective length.

But one important difference between the exposed end connections and the embedded portion must be pointed

out, namely: In the embedded portion, or more exactly, that portion of the face conductors parallel to the shaft, the conductors short-circuited under the positive brush lie over or near (according to the nature of the winding, and also according to whether the pitch is so chosen as to yield a short or long-chord winding) those simultaneously short-circuited at the negative brush, whereas the two groups of corresponding *end-connections* are located entirely separately thus :—

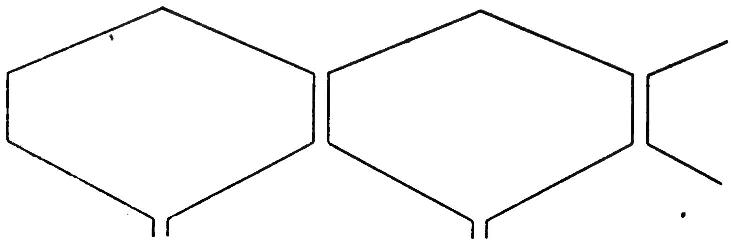

FIG. 7.

Hence the magneto-motive force, acting in the short-circuited coil, is twice as intense for the effective length as for the end-connections.

It has seemed best to designate by "embedded lengths" and "free lengths" respectively, the slot-enclosed portion and the end-connections, including with the latter that portion of the conductors parallel to the shaft, not strictly iron-clad—*i.e.*, that portion corresponding to the ventilating ducts and the insulation between the laminations. In the writer's design this makes a marked difference, the "effective lengths of laminations" often constituting less than 70 per cent. of the length of armature core over all.

In this free portion, where the conductors are parallel to the shaft, the magneto-motive force is also twice as intense per centimetre of length as for the end-connections. But rather than complicate the necessarily only approximate calculations, it is preferable to take a slightly higher value, namely—

$\cdot 8$ c.g.s. lines per centimetre of "free length."

This, together with the approximate value of 4 c.g.s. lines

per centimetre of embedded length, suffices to yield reliable approximate relative estimations of the total flux.

It is desirable here to illustrate the method of applying these constants.

Take a case where three turns are short-circuited under the positive, and three under the negative brush :—

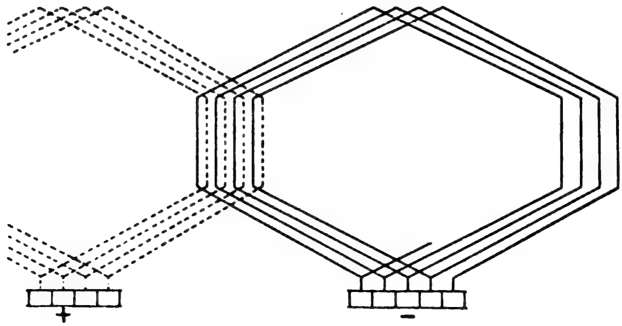

FIG. 8.

The mean length of one turn		100 cms.
The effective length of arm laminations		10 „
"Free length" per turn		80 „
"Embedded length" per turn		20 „
Lines per ampere-turn for "free length"	$= \cdot 8 \times 80 =$	64
Ditto "embedded length"	$= 4 \times 20 =$	80
Lines per *ampere* for "free length" ...	$= 3 \times 64 =$	192
Ditto "embedded length"	$= 6 \times 80 =$	480
Total lines linked with short-circuit turn		= 672

The inductance of one turn, in henrys, with relation to all the turns simultaneously short-circuited

$$= 672 \times 10^{-8} = \cdot 00000672 \text{ henrys.}$$

If the periodicity of reversal (twice the reciprocal of the time, in seconds, during which a given turn is short-circuited under the brush) equals 500, then the reactance equals

$$2\pi \times 500 \times \cdot 00000672 = \cdot 0212 \text{ ohms};$$

and if 100 amperes is the current to be reversed per set of brushes, then the reactance voltage per segment equals

$$100 \times \cdot 0212 = 2 \cdot 12 \text{ volts.}$$

The writer believes that here, for the first time, attention is called to two very interesting facts :—

1. That in the majority of modern machines, the inductance of the "free length" is a very considerable percentage, say 25 per cent. to 40 per cent., of the total inductance.

2. That, with the ordinary open slots with parallel sides of the proportions generally found in modern continuous-current generators, the inductance per centimetre of "embedded length" is generally only some four to six times greater than the inductance per centimetre of "free length."

These two considerations lead to another of still greater interest and importance, namely, that the inductance of a coil laid upon the surface of the armature—*i.e.*, on the lines formerly so frequently employed, and sometimes now-a-days termed "smooth core" construction—is, with customary proportions, rarely much less that one-third and often one-half or more as great as in the case of the same coil laid in a slot. This is readily seen from the case already illustrated; thus had the entire 100 cms. of mean length of one turn been "free length," the flux would have been—

$$\cdot 8 \times 80 \times 3 + \cdot 8 \times 20 \times 6 = 192 + 96 = 288,$$

about 43 per cent. of the value (672) obtained when 20 per cent. of the winding was embedded.

Of course in the old-fashioned types with but two, or at most but very few poles, the armature was very long and the end-connections but a relatively very small percentage of the mean length of a turn; but in most of the modern machines, such as the latest multipolar generators built by Mather & Platt, Westinghouse, General Electric Company, Schuckert, and many others, the general tendency is toward narrow armatures of large diameters, and the proportions of end-connections will be found to be not widely dissimilar from those represented by the case taken.

In connection with some investigations which Mr. Parshall and the writer are making in the subject of "Alternating-Current Design," some tests were made for the purpose of arriving at rough practical constants for determining the decrease in the inductance, accomplished by the subdivision of a given number of turns in many slots. Some of the results for the position of minimum

inductance have considerable bearing upon this question of the reactance voltage in commutating dynamos, and hence it is proposed briefly to explain sufficient portions of the investigation to enable these results to be described.

Five sets of punchings were prepared, of the same external size, but with different numbers of slots, namely with 2, 4, 6, 8 and 12 slots, this corresponding to 1, 2, 3, 4 and 6 slots per pole-piece. The slots were so proportioned that the ratio of width to depth was the same for all five models.

The punchings were cut from annealed transformer iron about 0·38 mm. thick and built up to a depth of 63· mm. Each lamination was japanned on one side only, and the japanning may be taken as corresponding to some 10 per cent. of the total depth. The laminations were held together by end plates of manganese steel 6·4 mm. thick, bolted together by means of insulated brass bolts. The coils were wound on formers, taped up and forced into the slots. The wire used was No. 14 S.W.G. (2·04 mm. bare diameter) and 144 turns were wound on each set, the total turns being evenly distributed among the slots. Photographs of the five sets are shown in Figs. 9, 10, 11, 12 and 13.

The data contained in Table XV. relates to these five models.

TABLE XV.

Size of Slot in mm.	Number of Slots.	Number of Coils.	Turns per Coil.	Total Turns.	Measured Resistance (ohms at 20° C.).	Corres. mean length of Turns (cms).
36·8 × 24·2	2	1	144	144	·33	43
26·2 × 17·2	4	2	72	144	·31	41
21·4 × 14·0	6	3	48	144	·29	38
18·4 × 12·1	8	4	36	144	·31	41
15·0 × 9·9	12	6	24	144	·31	41

While fundamental *quantitative* results were not the purpose of these tests, the models being so small, it may

Fig. 9.

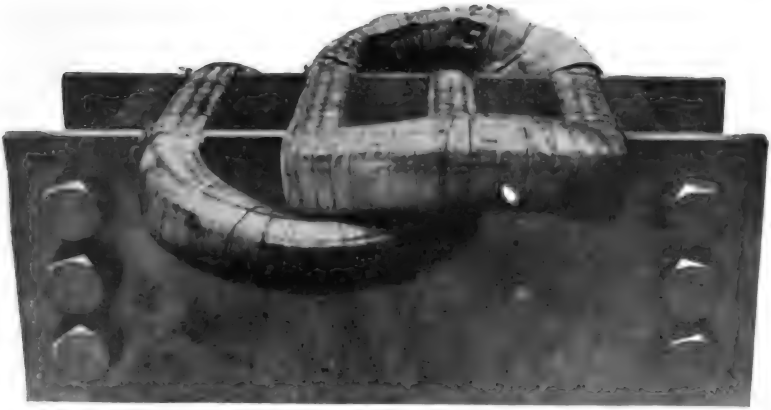

Fig. 10

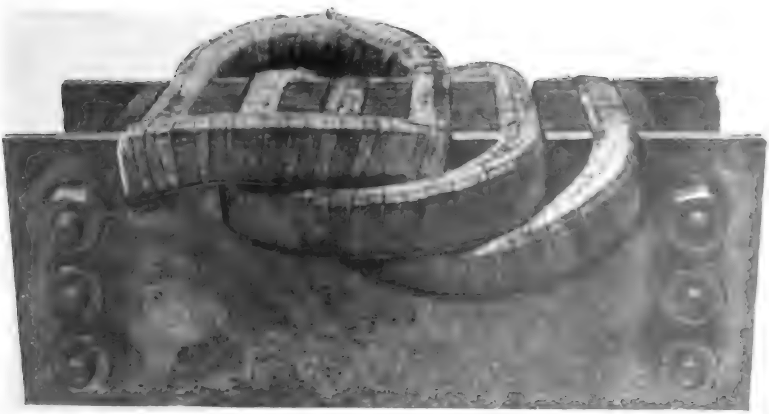

Fig. 11

FIG. 12.

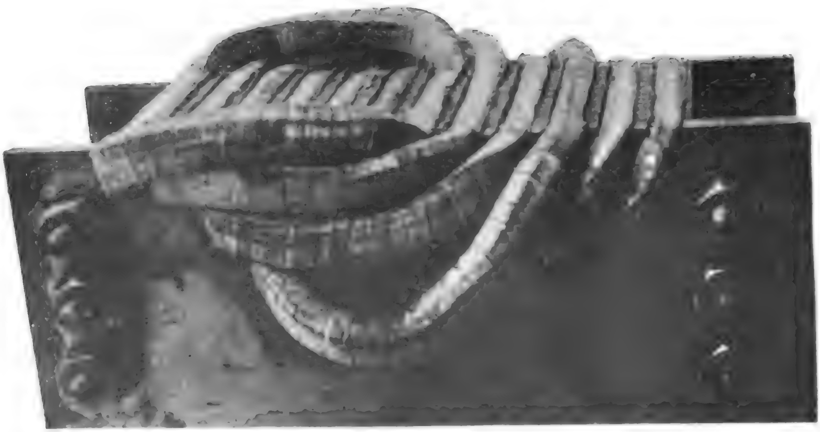

FIG. 13.

be pointed out that the approximate equivalent diameter is 13 cms. and the approximate equivalent cross-section of coil for the first model is about 3 cms. square. For such dimensions, Professor Perry's formula would not apply. One would, however, infer from the shape of the curves of Figs. 2 and 3 that there would be, probably, not over 0·3 c.g.s. lines per centimetre of free length for the uni-slot model, and still less for the other models, hence the magneto-motive force of the "free length" would not affect the results by more than some 10 to 20 per cent. at the most.

In the curves of Fig. 14 are given the results obtained

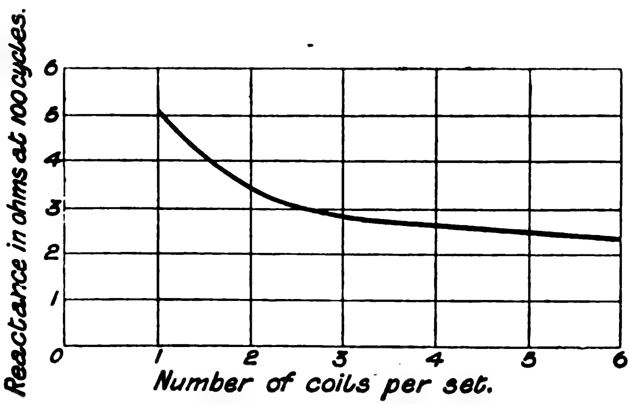

FIG. 14.

for these models when measured without any pole-pieces, which corresponds closely to the condition of minimum inductance, *i.e.*, the condition in coils at the instant of commutation under the brushes. It is interesting to observe that, for the six-coil model, the reactance is still 45 per cent. of the uni-coil model, and when it is pointed out that these two models represent very extreme cases, one will be inclined to admit that, with the very much smaller variations in shape and numbers of slots encountered in practice in continuous-current machines, the value of the inductance as expressed in flux per ampere-turn per centimetre of length will not be greatly different throughout the range of proportions common in the modern projection type of continuous-current dynamo.

In fact, while the two cases sketched in Fig. 15 represent diagrammatically the cases of models 1 and 5, the most extreme cases which would be met with in practice in continuous-current dynamos—as relates to coils simultaneously commutated—would not vary from one another so much as the two depicted in Fig. 16.

The writer has gone into this matter at such length, because it has considerable bearing upon his contention

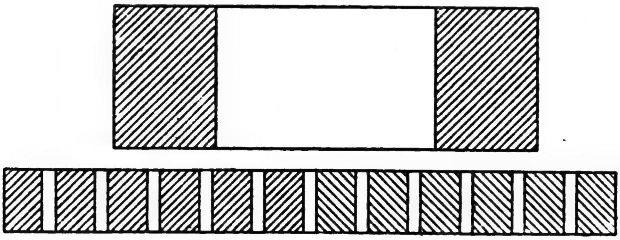

FIG. 15.

that one is justified, without much regard to the slot proportions or the numbers of slots, in taking a representative value as he has done, say four lines per ampere-turn per centimetre of embedded length, in instituting comparisons of the reactance voltage of various machines.

If one analyses the results of the curve of the Fig. 14, changing the values into c.g.s. lines per centimetre of

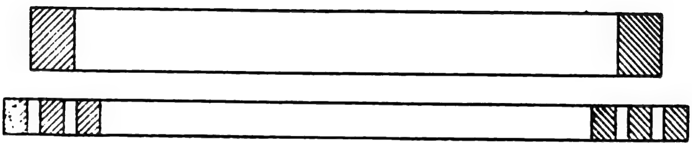

FIG. 16.

embedded length and neglecting the free length, one obtains the results given in the curve of Fig. 17. Treating the entire 6·3 centimetres between flanges as magnetic iron, *i.e.*, neglecting the 10 per cent. of insulation between plates, tends to offset the error involved in failing to assign a portion of the total lines to the influence of the "free length." But, as already stated, the models are too small to serve suitably for a basis for obtaining useful fundamental constants of this sort, being intended for ascertaining the approximate percentage decrease in the reactance secured

by distributing a winding of a given number of turns, in many slots.

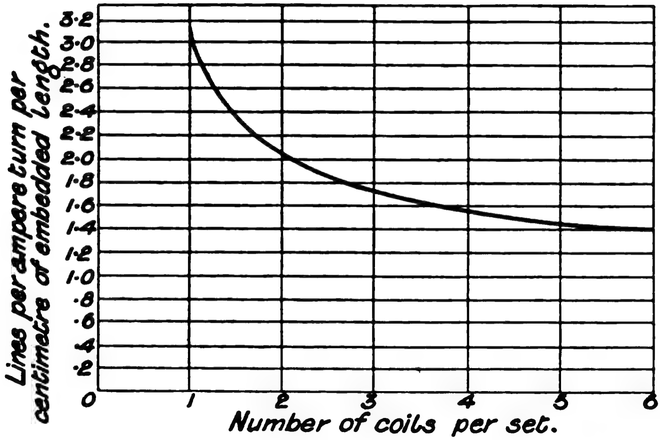

FIG. 17.

For the purpose of studying the extent of the influence of the shape of the slot, the writer had built a series of models of the dimensions and with the windings shown in Fig. 18. The inductance tests made upon these five models give the results set forth in Table XVI.

TABLE XVI.

Model.	Width of Slot (Millimetres).	Depth of Slot (Millimetres).	Width ÷ Depth.	A. Observed Inductance (henrys).	B. Inductance corrected to correspond to more normal wave form (henrys).	C. Lines per ampere-turn corresponding to column B.
I.	—	—	—	·000280	·000243	169
II.	20	15	1·33	·000365	·000317	220
III.	15	20	·75	·000400	·000347	242
IV.	10	43	·23	·000495	·000430	299
V.	5	6c	·083	·000805	·000700	485

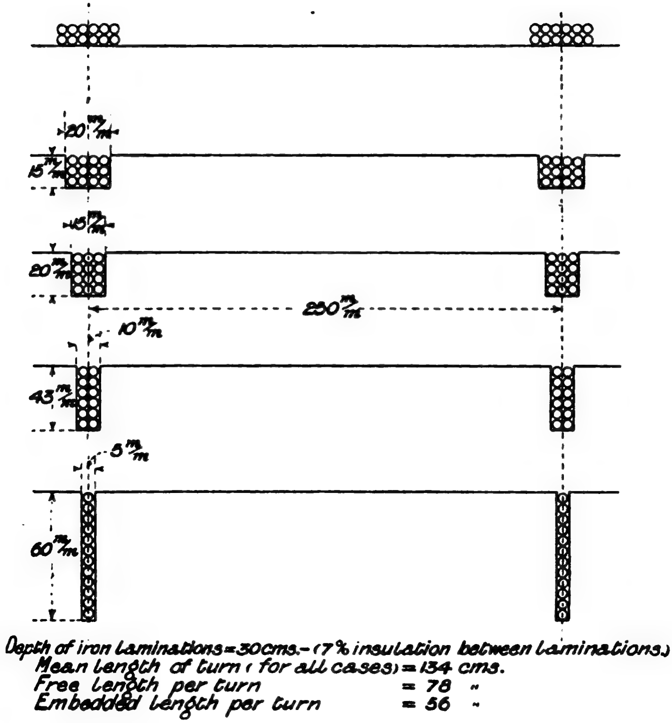
20 m/m
15 m/m
15 m/m
20 m/m
230 m/m
10 m/m
43 m/m
5 m/m
60 m/m
Depth of iron laminations = 30 cms. – (7% insulation between laminations.)
Mean length of turn (for all cases) = 134 cms.
Free length per turn = 78 "
Embedded length per turn = 56 "

FIG. 18.

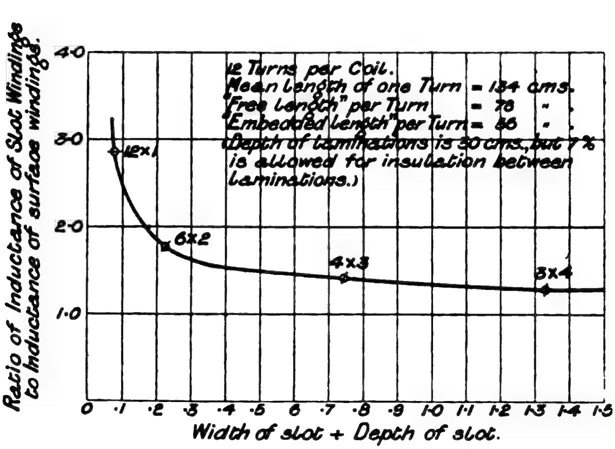
12 Turns per Coil.
Mean Length of one Turn = 134 cms.
"Free Length" per Turn = 78 "
"Embedded Length" per Turn = 56 "
(Depth of laminations is 30 cms., but 7% is allowed for insulation between laminations.)
12×1
6×2
4×3
3×4
Ratio of Inductance of Slot Windings to Inductance of surface windings.
4·0
3·0
2·0
1·0
0 ·1 ·2 ·3 ·4 ·5 ·6 ·7 ·8 ·9 1·0 1·1 1·2 1·3 1·4 1·5
Width of slot ÷ Depth of slot.

FIG. 19.

In Fig. 19, the inductance of Model I., corresponding to the case of a smooth-core winding, is taken as 1·0, and the relative values for the other models are plotted in terms of the ratio of the width to the depth of the slot. From the curve it is seen that considerable changes in the slot proportions are necessary even slightly to affect the inductance of the winding. Furthermore, since in these models the "embedded length" has the high value of 45 per cent. of the total length per turn, the shape of the slot would, in actual machines, be even less influential, since in them the "embedded length" rarely exceeds 30 per cent. of the total length, and the inductance of the remaining 70 per cent. constituting the "free length" is, of course, nearly independent of the shape of the slot.

If for the models of Fig. 18 we estimate the inductance of the "free length" at 0·8 lines per centimetre, then for the "embedded length," working from column C of Table XVI., the results set forth in Table XVII. are obtained for the inductance per centimetre of "embedded length."

TABLE XVII.

Model.	Lines per Centimetre of "Embedded Length."
II.	2·8
III.	3·2
IV.	4·2
V.	7·5

It must not be forgotten, in considering these results, that very extreme cases were examined.

Then tests were made with a coil, whose height equalled the whole depth of the slot, of which the inductance was measured, first with the coil at the bottom of the slot, and then in positions successively higher and higher, until finally the coil was entirely removed from the armature. The results are shown in the curve of Fig. 20.

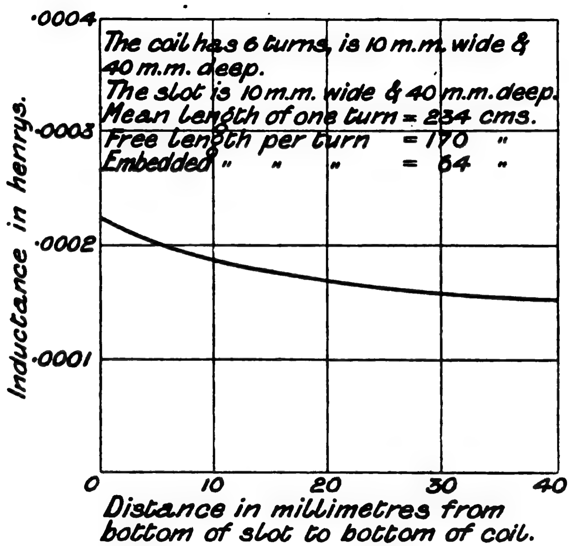

FIG. 20.

We may analyse this case as follows:—

Lines per ampere for "free length" ...	$= 170 \times \cdot 8 \times 6 =$	815
Lines per ampere for "embedded length"	$= 64 \times 4 \times 6 =$	1,540
Total flux (C.G.S. lines)	=	2,355
Estimated inductance $2355 \cdot \times 6 \times 10^{-8}$	= ·00014 henrys	
Observed inductance with a coil 40 mm. × 10 mm. in one slot with abnormal wave-form supplied	= ·00022 „	
Corrected 15 per cent. for more normal wave-form	= ·00019 „	

Had the coil been rather spread out, say part in one slot and part in the adjoining slot—this representing a more average practical condition—this 36 per cent. excess of the corrected observed result over the estimated result, would have been decreased.

In the preceding test, the "embedded length" was only 27 per cent. of the mean length per turn. This tended to

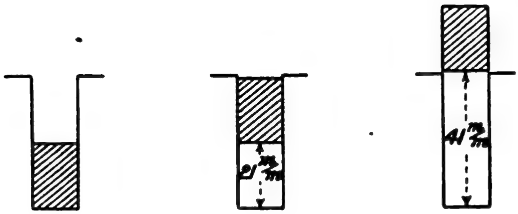

FIG 21.

obscure the influence of the depth in the slot of the "embedded length." Another test was made upon a 5-turn coil [1] of which the

Mean length of turn	... =	105· cms.
"Free length" per turn	... =	56· cms.
"Embedded length" per turn	=	49· cms.

The "embedded length" thus constituting the high proportion of 47 per cent. of the mean length per turn.

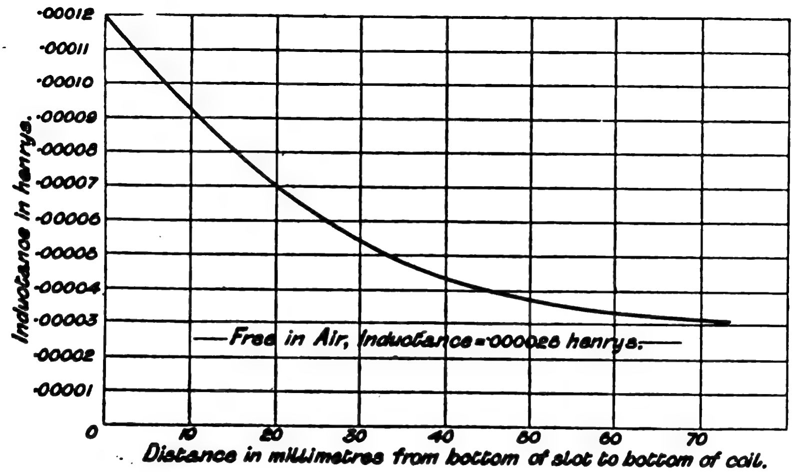

FIG. 22.

[1] It is to be observed that the height of this coil equalled only half of the depth of the slot, while in the preceding case the height of the coil equalled the whole depth of the slot.

Measurements were made in four positions of the coil :—

1. Coil at the very bottom of the slots.
2. Top of coil just level with top of slot.
3. Bottom " " "
4. Coil free in air.

The coil was 20 mm. high × 10 mm. wide.
The slot was 41 mm. high × 10 mm. wide.

The three first positions are shown in Fig. 21 and the results are given in the curve of Fig. 22.

Effect of End-Connections.

Tests with coils with different lengths of end-connections were then made on the three 5-turn coils shown in Fig. 23.

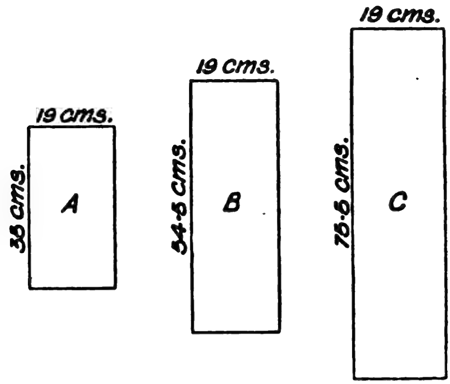

Fig. 23.

For all three cases the "embedded length" was 49 cms. The coils were all of a section of 10 mm. wide by 20 mm. deep, and were measured in slots 10 mm. wide by 41 mm. deep. Three sets of measurements were made with the coils respectively at the bottom, at the top, and directly above the slots. The results are given in Table XVIII.

TABLE XVIII.

Coil.	Length of one Turn in centimetres.	"Free length" in centimetres.	"Embedded length" in centimetres.	Ratio of embedded length to free length.	Inductance, with Uni-slot Alternator, in henrys. Coil at bottom of Slots.	Top of Coil level with top of Slot.	Bottom of Coil level with top of Slot.
A	105	56	49	·47	·000120	·000070	·000041
B	147	98	49	·33	·000124	·000079	·000054
C	189	140	49	·26	·000142	·000093	·000068

These results are plotted in three of the curves of Fig. 24. The fourth curve is interpolated for the case of a coil lying half-way between top and bottom of the slot, but even this would not be the practical equivalent of an actual armature winding, since then, considering coils short-circuited at

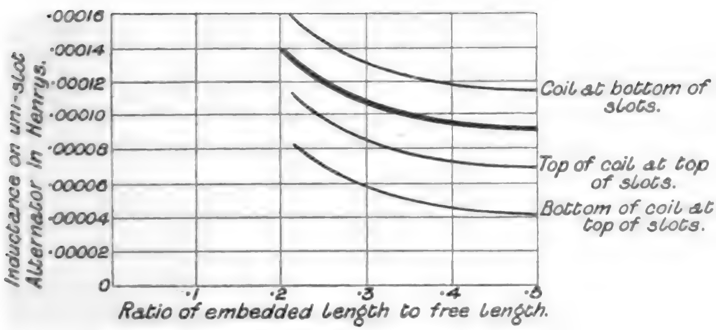

FIG. 24.

both the positive and negative brushes, the group of conductors concerned, occupies the whole depth of the slot, and generally two neighbouring slots are concerned. For these reasons as well as because the measurements were made on the circuit of the uni-slot alternator, the results are considerably too high.

It will nevertheless be of interest to analyse the case equivalent to this fourth curve :—

1. When the 49 centimetres of "embedded length" constitute 20 per cent. of the length per turn:—

Lines set up by 196 cms. of "free length" ...	$= 196 \times \cdot 8 \times 5 =$	784
Lines set up by 49 cms. of "embedded length"	$= 49 \times 4 \times 5 =$	980
Total c.g.s. lines linked with coil	$=$	1,764
Inductance for sine form of wave $= 1{,}764 \times 5 \times 10^{-8}$ ...	$=$ ·000088 henrys.	
Inductance from observations shown in Fig. 24	$=$ ·000138 ,,	
Ditto corrected 15 per cent. for wave form	$=$ ·000120 ,,	

leaving 36 per cent. to be accounted for by the less height of the coil, and by its not being spread out as it would be in an actual machine.

2. When the 49 cms. of "embedded length" constitute 50 per cent. of the length per turn:—

Lines set up by 49 cms. of "free length" ...	$= 49 \times \cdot 8 \times 5 =$	196
Lines set up by 49 cms. of "embedded length"	$= 49 \times 4 \times 5 =$	980
Total lines linked with coil	$=$	1,176
Inductance for sine form of wave $= 1{,}176 \times 5 \times 10^{-8}$ ...	$=$ ·000059 henrys.	
Inductance from observations shown in Fig. 24	$=$ ·000092 ,,	
Ditto corrected for wave form	$=$ ·000080 ,,	

leaving, as before, 36 per cent. to be accounted for by the other respects in which it differs from the conditions of practice.

It might at first sight be objected to the method employed by the writer for estimating the reactance voltage that it takes liberties with the general ideas of magneto-motive force in so considering the magneto-motive force per unit of length of coil, instead of considering merely ampere-turns. The observations already described dispel

this objection fairly effectively. The following test still further justifies the method pursued :—

A coil was successively widened out to span more and more armature slots of a given core, and corresponding measurements of the inductance were made. The results shown in the curve of Fig. 25 show comparatively little variation until the coil became extremely narrow.

A similar test was made on the same coil when entirely free in air. It was successively narrowed up from an original width of 70 cms. down to a final width of only 20 centimetres. The value of the inductance in the final

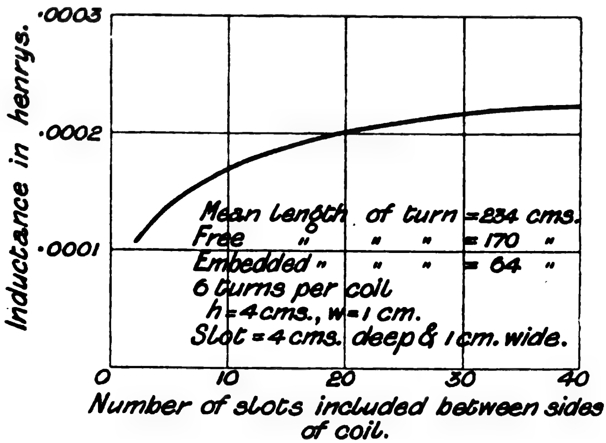

FIG. 25.

form is still 80 per cent. as great (expressed in c.g.s. lines per ampere-turn per centimetre of mean length of turn) as for the 3·5 times greater width of the coil in its original form. The results are plotted in the curve of Fig. 26.

It may be thought that the results of this collection of inductance tests point to the advisability of using throughout some 10 per cent. to 20 per cent. higher constants in estimating the reactance voltage. The writer would not be inclined to share this opinion. However, he attributes but little importance to any other than the *relative* values. If more satisfactory tests were at his disposal, pointing conclusively to higher values, corresponding to the actual conditions of practice, it would in no way affect his conclusions as to the relative merits of various machines, and

he would merely scale up the numerical values of the reactance voltage and for the limiting safe values by 10 per cent., 20 per cent., or whatever still higher increase seemed justified, throughout the list. As to the relative influence of the "embedded" and "free length," the tests seem very conclusively to indicate the correctness of the ratio which the writer employs. Further data for revising the constants employed would be very welcome, since the writer fully realises the meagreness and lack of definiteness of the data here set forth. But the tests appear qualitatively to bear out very strikingly indeed the ideas underlying the

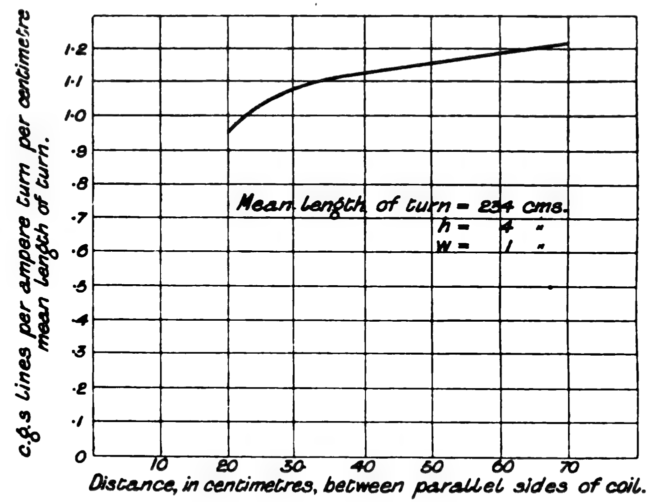

FIG. 26.

method set forth, and the writer is of the opinion that where they conflict quantitatively it is due to the unavoidably rough character of factory tests, made, as they are, under conditions only permitting of taking a minimum number of measurements, and these with workshop instruments at moments when the exigencies of regular commercial testing permit. It was absolutely out of the question for the writer to give the tests any personal supervision further than to indicate in the first place the nature of the tests he required.[1]

[1] This method of estimating the reactance voltage is based upon substantially the same principles as the method published two years ago by Mr. H. F. Parshall and the present writer. The novelty in the method, as

The "two-circuit"- or "series"- or "wave"-winding is not so readily analysed in this way. The writer prefers to make the calculation precisely as if it were a "multiple-circuit" winding; that is, ignoring the *actual* sequential connections of the face conductors, he treats the case just as if the connections were those described above, remembering, however, to derive the reactance voltage from the larger current which, in such windings, flows in each conductor. Furthermore, the writer's experience with these windings has been that it is desirable to keep within rather lower limits for the reactance voltage per segment. This is still more the case for "multiple"-windings (*i.e.*, "double"- "triple"-, etc.), including those of the multiple-circuit type, but more especially for the two-circuit multiple windings. In multiple-circuit multiple windings one must also remember that the frequency of commutation and the number of turns simultaneously short-circuited under the brushes have to be determined by remembering that for, say, a double winding, the intermediate commutator segment has to be considered as added to the width of the two bounding insulations. Hence in such windings, for a given width of brush, the frequency of commutation is much higher than for a single winding.

Having studied this method in connection with a good many machines the writer finds that, with careful proportions in other respects, one may be very sure of excellent results with reactance voltages of not over 3 volts. Above 3 volts, except in the case of large slow-speed machines, one is liable to encounter trouble, which, however, if the value is not much in excess of 3 volts, is generally attributable to some other cause. Some of these causes are :—

1. High ratio of pole arc to pitch, which results in too narrow a commutating zone.

then described by them, consisted chiefly in starting from the basis of representative values for the inductance as expressed in terms of the lines set up per ampere-turn per unit of length of laminations, and it led to substantially the same results as one obtains by the method in its present form, wherein the chief additional novelty consists, as has already been set forth, in allocating the components of the inductance in the "free" and "embedded" lengths respectively, in giving guiding values for estimating these components, and in supporting them by fairly thorough tests and by the results of experience gained in applying the method to a great variety of machines.

2. A number of commutator segments, for a multiple-circuit winding, not a multiple of the number of poles. With relatively large numbers of segments per pole this is not harmful, except that it prevents the use of equaliser rings, but with a small number of segments per pole it is to be avoided.

3. Inequality in the air gap.
4. Inequality in the material of the magnetic circuit.
5. Unsymmetrically assembled commutator segments.
6. Unsymmetrically mounted brush gear.
7. Unsuitable type of brush holder.
8. Incorrect brush tension.
9. Inexact alignment of brushes.
10. Insufficient brush surface.
11. Brushes not suitably bedded.
12. Unsuitable quality of carbon brush.
13. Hard mica insulation between segments.
14. Soft commutator segments.
15. Insufficiently rigid machine foundations.
16. Insufficiently rigid shaft.
17. Insufficiently rigid commutator construction.
18. Eccentricity in commutator.
19. Insufficiently clean commutator surface.
20. Inequality in angular speed of prime mover.

On large, slow speed, direct-connected machines the permissible limit for the reactance voltage increases considerably with the size of unit. Thus for speeds of from 80 to 120 r.p.m. 3 to 4 volts may be used with perfect success for the range from 400 to 800 k.w., and the writer has occasionally seen machines of these rated outputs and speeds, where the values went as high, at full rated load, as 6 volts. But they were not really excellent, and had not much margin of overload capacity, and the writer believes that it would be well throughout this range, and even to considerably beyond 1,000 k.w. units, not to exceed 4·5 volts, or at the most 5 volts. It is, however, impossible, in these large sizes, without departing widely from customary constructions, to have such low values as in smaller machines. The writer's own rule is simply to make the reactance voltage as low as considerations of economy and efficiency

will permit. It is often practicable to obtain reactance voltages of from 1 to 2 volts, and where no other features are sacrificed by so doing this is of course always very desirable. The commutation cannot be too good.

As to why the larger sizes are rather less sensitive to high reactance voltages, the writer must freely confess that he has never yet found a satisfactory explanation. It would be an interesting field for investigation, and the results would be of great value to ascertain whether the three components of the reactance voltage, namely the flux, the frequency, and the current, should all be given the same weight,[1] and also whether some substitute for the method stated for estimating the frequency might not be more correct. The formula—

$$\text{Reactance voltage} = 2\pi n l C,$$

is, on account of the sine wave assumption involved, of course only remotely likely to be the most suitable, but it is used for want of knowledge of any suitable substitute.

The writer recently went through a very large number of machines, suggesting modifications and improvements, and at the same time adding to the system some new designs of both small and large machines. Especial attention was given to improvement in commutation, hence interest attaches to Table XIX., in which are set forth for twenty-eight of them the normal ratings and some leading constants and dimensions. In the case of many of the small sizes they were only arranged with such modifications as it was practicable to make without too expensive changes, and hence the proportions are rarely such as one would select for new designs. Nevertheless the table serves to indicate what the writer regards as safe values from the commutating standpoint for the speeds, voltages, and outputs set forth. Before these small machines were re-arranged the reactance voltages were in many cases several times as great, and they were decidedly poor as regards commutation. Many machines are now being produced by various firms in which similar conditions obtain, and in which rearrangement of the windings and commutators

[1] A large number of subsequent comparisons show that these components should all be given the same weight.

TABLE XIX.

Reference No.	Number of Poles.	Kilowatts Output.	Speed—r.p.m.	Voltage.	Armature Reaction in total ampere turns per pole.	Reactance Voltage.	Average Volts per Segment.	Number of Slots.	Width of Slot (mm).	Depth of Slot (mm).	No. of Commutator Segments.	Turns per Segment.	Type of Winding 2-Circuit or Mult. Circuit (Single).	Depth of Air Gap (mm).	Commutator Diameter (cms.)	Thickness of Commutator Segment at surface (mm.)	Diam. of Armature (cms.)
1	4	5 H.P.	900	110	1000	2·1	6·6	67	6·1	15	67	3	2-Circ.	2·5	16	6·7	22
2	4	5 H.P. Motors.	900	220	1000	2·8	10·9	27	11	18	81	5	2 ,,	2·5	16	5·4	22
3	4	7½ H.P.	850	110	1300	1·8	7·2	61	7·6	19	61	3	2 ,,	2·5	19	9·0	25
4	4	15 H.P.	700	220	1760	1·7	7·2	41	13	18	123	2	2 ,,	3·5	24	5·4	30
5	4	10	930	550	1330	2·8	11·3	65	9·5	19	195	3	2 ,,	4	26·7	3·6	33
6	4	13½	1400	550	1200	2·5	11·3	65	10	15	195	2	2 ,,	4	26·7	3·6	33
7	4	14½	825	550	1460	2·8	15·0	49	10·4	19·5	147	3	2 ,,	4	26·7	5·0	33
8	4	18½	770	550	1930	2·5	14·4	51	11	22	153	3	2 ,,	4	27·9	5·0	41
9	4	30	600	115	3880	1·4	3·9	119	7·5	17	119	1	2 ,,	5	45	11·1	52
10	4	27	715	550	2320	2·4	11·6	63	12·6	18	189	2	2 ,,	4·5	32·5	4·7	46
11	4	40	600	115	3780	1·7	5·3	87	8·5	20	87	1	2 ,,	5	35·6	12·1	52
12	4	30	600	230	2890	1·1	5·2	59	15	15	177	1	2 ,,	5	45·0	7·2	52
13	4	35	975	230	2450	1·7	7·1	43	15·2	17	129	1	2 ,,	4·5	38·1	8·5	46
14	4	33	660	550	2680	1·5	6·2	119	8·0	20	357	1	2 ,,	5	45·0	3·2	52
15	4	33	1100	550	2000	2·0	8·2	89	7·2	17	267	1	2 ,,	4·5	38·1	3·7	44
16	4	38	1070	550	2150	1·7	8·8	83	8·6	19	249	1	2 ,,	4·5	38·1	4·0	46
17	4	50	1020	550	2700	1·6	9·3	79	9	18	237	1	2 ,,	5	38·1	4·3	52
18	4	60	960	550	3230	2·1	9·3	79	10·5	18	237	1	2 ,,	5	38·1	4·3	52
19	4	45	925	230	3000	1·8	7·6	121	5·9	21	121	1	2 ,,	5	38·1	9·1	52
20	6	40	240	110	3800	1·9	1·8	125	9	27	125	1	2 ,,	5	38·1	8·8	68
21	6	75	500	600	3340	2·2	11·3	160	7	33	320	1	2 ,,	5	48·2	4·8	67
22	6	130	500	110	3800	2·2	5·7	116	9	26	116	1	6 ,,	6	63·5	16·4	85
23	8	80	750	115	3500	2·0	2·9	84	12·1	27·5	336	1	8 ,,	5	48·0	3·7	68
24	8	250	100	550	7800	2·2	4·0	364	9·6	29	1092	1	8 ,,	9	105	4·7	187
25	8	300	375	550	5000	2·9	7·7	192	10	29	576	1	8 ,,	8	95	5·2	150
26	8	400	100	550	9000	2·8	5·6	264	12·3	33	792	1	8 ,,	10	105	6·6	230
27	16	1000	90	500	9000	3·9	7·7	384	13·4	32	1152	1	16 ,,	10	270	7·4	350
28	22	1600	84	550	8000	3·8	9·2	440	14·0	34	1320	1	22 ,,	10	350	7·6	450

would permit of radical improvement in commutation. And in no feature of the design is it of greater importance to keep well on the safe side than with respect to commutation constants. Many of those quoted in the list are unnecessarily low, but so long as these low constants can be obtained without sacrifice in other directions, and (in the writer's opinion) even at slight sacrifice in other directions, it is to be recommended. For instance, in the last few designs in the list, namely the large, direct-connected machines, the efficiencies at full load and half load are some ½ per cent. lower than might have been obtained for a given cost of material, by going 25 per cent. or so higher with the reactance voltage.

In the specifications in Tables XX., XXI., and XXII. are given more complete data of the writer's designs for slow speed direct-connected units of 400 k.w., 1,000 k.w., and 1,600 k.w. The guarantee to which they comply is as follows :—

Guarantee : 25 per cent. overload during one half-hour, without harmful sparking or heating. Thermometrically measured temperature increase not over 50° Cent. above surrounding atmosphere during continuous operation at rated load. No harmful sparking or heating with momentary overloads of 50 per cent. Fixed brush position for all these conditions. Insulation of entire machine from copper circuits to iron, to withstand the application of a R.M.S. potential of 4,000 volts for one minute at 20° Cent.

There has lately been a good deal of discussion with regard to the practicability of obtaining good results as regards sparking in large high-speed dynamos for direct coupling to high-speed engines. In the writer's opinion, this is purely a question of adopting sufficiently solid (and consequently expensive) mechanical construction throughout, to permit of an absolutely true running commutator of high peripheral speed, both commutator and brush supports being completely free from vibration. Take, for instance, a large 500-volt unit, which would be the most difficult case for high speed. With a sufficiently large commutator diameter and sufficiently narrow segments, there may be high armature strength per pole. The high speed, high armature strength per pole, together with a rather large number of poles, will result in requiring but a very small

TABLE XX.

Specification.	400 K.W.	1000 K.W.	1600 K.W.
Number of Poles	8	16	22
Kilowatts rated output	400	1000	1600
Speed—revolutions per minute	100	90	85
Full load voltage	550	500	550
Full load amperes	730	2000	2900
External diameter of the armature (centimetres)	230	350	450
Length armature over winding (centimetres)	95·0	80·0	72·0
Length over armature core (centimetres)	40	35	33
Number of ventilating ducts	8	8	7
Width of each duct (millimetres) ...	13	13	13
Effective length of laminations in armature core (centimetres)... ...	27	22·5	21
Internal diameter of armature laminations (millimetres)	140	281	375
Diameter of commutator (centimetres)...	165	270	350
Length of commutator (centimetres) ...	32	38	27
Width of segment at surface (excl. insulation) (millimetres)	6·6	7·4	7·6
Thickness of insulation between segments	0·76	0·76	0·76
Total number of segments	792	1152	1320
Total number of slots	264	384	440
Segments per slot	3	3	3
Turns per segment...	1	1	1
Width of slot (millimetres)	12·3	13·4	14
Depth of slot (millimetres)	33	32	34
Radial depth of air-gap (millimetres) ...	9	10	10
Radial length of magnet core (centimetres	45	48	50
Diameter of magnet core (centimetres)...	45·5	38·0	38
Cross-section of magnet core (square centimetres)	1630	1140	1130
Pole-face dimensions (centimetres) ...	40 × 61	35 × 49	33 × 47
Ratio of pole arc to pitch	0·67	0·71	0·72
External diameter of magnet yoke (centimetres)	379	531	644
Width of magnet yoke (centimetres) ...	66	70	90
Radial thickness of magnet yoke (centimetres)	21	30	38
Width of armature conductor (millimetres)	2·4	2·8	3·0
Height of armature conductor (millimetres)	13	12·5	13·5
Current density in armature conductor (amps. per sq. centimetre) ...	303	357	330
Thickness of armature slot insulation (copper to iron) (millimetres)...	1·6	1·6	1·6
"Space factor" in armature slot	0·46	0·49	0·51

TABLE XXI.

Specification.	400 K.W.	1000 KW.	1600 K.W.
Average voltage per commutator segment	5·6	7·7	9·2
Amperes per sq. cm. of brush contact	5·0	5·0	5·0
Total reaction in armature ampere-turns per pole	9000	9000	7,900
Type of winding	8-Circ. Single	16-Circ. Single	22-Circ. Single
Paths through armature winding from positive to negative brushes...	8	16	22
Amperes per path	91	125	132
Length of arc of brush contact (millimetres)	23	20	33
Frequency of commutation, cycles per second	190	318	236
Mean length of armature turn (centimetres)	300	240	220
Embedded length per turn (centimetres)	54	45	42
Reactance voltage with full load amperes	2·8	3·9	3·7
Apparent tooth density (lines per sq. cm.)	21,000	22,700	23,000
Width of tooth at root (millimetres) ...	14·3	14·7	17·6
Radial depth laminations below slots (centimetres)	42	31	34
Density below slots (lines per sq. cm.)	10,300	10,700	10,500
Cycles per second for reversal of magnetisation in armature iron ...	6·7	12·0	15·6
Total arm. flux at full load and rated terminal voltage (megalines)...	21·7	14·9	15·1
Assumed factor for magnetic leakage ...	1·125	1·125	1·125
Flux in magnet cores (megalines) ...	24·4	16·8	17·0
Density in magnetic cores (lines per sq. cm.)	15,000	14,900	15,000
Density in magnet yoke (lines per sq. cm.)	11,100	4,000	5,400
Pole-face density (lines per sq. cm.) ...	8,900	8,700	9,900
Ampere-turns on open circuit but full load voltage	10,000	11,000	13,000
Ampere-turns at full load amperes and volts	13,500	14,000	16,000
Ampere-turns for overcoming armature reaction	3,500	3,000	3,000
Material of magnet yoke	Cast Steel	Cast Iron	Cast Iron
Material of magnet cores	Cast Steel	Cast Steel	Cast Steel
Material of magnet pole-faces	Cast Iron	Cast Iron	Cast Iron
Material of armature sheets	Steel	Steel	Steel
Peripheral speed of armature (metres per second)	12·0	16·5	20·0
Peripheral speed of commutator (metres per second)	8·7	12·7	15·6
Centrifugal force at armature surface in kilogrammes per kilogramme	13·0	16·0	18·0
Centrifugal force at commutator surface in kilogrammes per kilogramme	9·0	12·0	14·0

TABLE XXII.

Specification.	400 K.W.	1000 K.W.	1600 K.W.
Losses and Efficiencies at 60° Cent.			
Core loss	9,000	18,000	32,000
Armature copper loss	13,100	24,200	24,400
Commutator C^2R loss at brush contacts	16,000	4,400	5,800
Allowance for stray losses in commutator	100	200	300
Commutator brush friction loss	700	2,800	5,300
Loss in shunt winding	4,400	8,250	13,000
„ series „	1,600	2,250	3,000
„ shunt rheostat	650	1,250	2,000
„ series diverter rheostat	600	750	1,000
Total of constant losses	14,850	30,500	52,600
„ variable losses	16,900	31,600	34,200
„ all losses	31,750	62,100	86,800
Commercial efficiency at full load ...	92·6	94·1	94·9
„ „ „ ¾ „ ...	92·5	94·0	94·4
„ „ „ ½ „ ...	91·4	92·9	92·8
„ „ „ ¼ „ ...	86·4	88·5	88·1

The Commutator losses are figured on a brush resistance of 0·2 ohms per square cm., a brush pressure of 0·1 kg. per square cm., and on a friction co-efficient of 0·3.

Watts per square decimetre of peripheral radia. surface of armature at 60° C.	31	48	57
Watts per square decimetre of peripheral radia. surface of commutator at 60° C.	17	25	43
Watts per square decimetre of exter. cylindrical radia. surface of field spools at 60° C....	9	9	9

Weights and Costs in Kilogrammes and Shillings.

Armature laminations	5,500	5,300	7,700
„ copper	660	900	1,100
Commutator segments	730	1,700	1,700
Field copper	900	1,570	2,700
Pole faces	700	1,000	1,200
Magnet cores	4,300	7,000	10,000
Total magnet yoke (including feet) ...	12,400	27,000	33,000

Taking for costs per kilogramme, the rough values of two shillings per kg. for copper, 0·31 for laminations, 0·38 for cast steel and 0·25 for cast iron, the totals for the cost of "net effective material" are:—

Total cost of "net effective material" in shillings	12,800	19,500	25,800
Total weight of complete machine exclusive of shaft (kilos.) ...	32,000	62,000	77,000
Cost of "net effective material" per k.w. in shillings	32·0	19·5	16·1

magnetic flux per circuit, and hence the machine will be very narrow. A narrow machine with many segments per pole, and consequently low average voltage per segment, will also, in spite of the high commutation frequency, be characterised by low reactance voltage, which, with the stable mechanical construction above set forth, will result in a machine with excellent commutating properties. Indeed it occurs to the writer to point out here that probably one of the most characteristic novelties of his designs —if such slight departures from preceding designs may be termed novelties—consists in the employment of fairly numerous poles combined with high armature strength per pole. Heretofore designers resorting to many poles appear generally to have done so with a view, firstly to securing economy in material, and secondly for the purpose of thereby minimising the armature ampere-turns per pole. The writer, in the interests of securing a low reactance voltage, is inclined to recommend a good many poles, and as many armature ampere-turns per pole as are consistent with suitable thickness of segment, available room on the armature surface, and permissible centrifugal stresses in armature and commutator. There appears to be a large field for such machines, which is developing as a result of the success which has been achieved with large high-speed engines. The possible economies may be judged by explaining that, for a given output, the factory cost for large 500-volt direct-connected dynamos decreases closely in proportion to the square root of the ratio of the speeds. This is no theoretical deduction, but the result of comparisons of the complete factory costs of a number of such machines. For lower-voltage dynamos the saving would not be quite so great as in this proportion, since the commutator must have a radiating surface and a brush-bearing surface practically as great for a high-speed as for a low-speed dynamo for a given output and voltage, since any increased advantage obtained at high speeds as regards ventilation is fully offset by the increased friction loss at the brushes. The amperes to be collected at the brushes, hence the brush contact C^2R losses are independent of the speed. Since the lower the voltage the greater the percentage of the total cost which the cost of the commutator constitutes, the saving due to increased speed cannot be so

marked in low voltage as in high voltage machines. This is analogous to the case of rotary converters, where the neutralising of the currents in the armature conductors shows its effect in decreased cost much more markedly in high voltage than in low voltage machines. Another tendency controlling the nature of the design selected for these high-speed dynamos is more of a commercial nature, namely, that the speeds are just about such as are very suitable for large, 25-cycle, rotary converters; and it is distinctly economical, where, as often occurs, no especial advantage is thereby sacrificed, to develop both of these classes of apparatus from the same models. Thus a 25-cycle, 400-k.w. 500-volt 6-phase rotary converter works out satisfactorily with 8 poles and 375 r.p.m., and this speed, with shortened commutator, yields an excellent 300-k.w. dynamo, although, if the rotary converter were not required, it is likely that six poles would be slightly preferable for a 500-volt, 300-k.w. generator at 375 r.p.m. Similarly a 10-pole, 650-k.w., 500-volt, 300 r.p.m. 6-phase rotary convertor, with minor changes, yields an excellent design for a 500-k.w. dynamo for the same voltage and speed.

In such carefully considered cases the writer is by no means averse to making compromises in the interests of standardisation in manufacturing.

It is probably not generally realised what a stupendous programme of ratings requires to be standardised—in continuous-current machines alone—by every large electrical manufacturing concern. We may consider the case of a single line of very small high-speed machines of from 125 kilogrammes weight, up to 2,600 kilogrammes weight. This may be provided for by some twelve distinct models, but when worked out to meet the demands of the market, with ratings as dynamos, motors and all the sub-divisions of these two classes, the list is found to comprise hundreds of ratings for which but few can, with any regard to the best results, be arranged to have precisely the same manufacturing specifications.

The twelve models of the range of weights mentioned, will, when rated as shunt motors with open frames, suffice for a range of outputs of from 2 H.P. to 65 H.P. for the lower of the customary range of speeds, and 3 H.P. to

75 H.P. for the highest customary speeds. But examining the different purposes for which the machines will be employed, there are found to be the following chief classifications, for each of which all the twelve models must be rated for three different voltages.

I.	Shunt-wound	Dynamos—	Low	Speed—	Open Type.
II.	„	„	High	„	„
III.	„	Motors	Low	„	„
IV.	„	„	High	„	„
V.	„	„	Low	„	Totally Enclosed Type.
VI.	„	„	High	„	„
VII.	Series-wound	„	Low	„	Open Type.
VIII.	„	„	High	„	„
IX.	„	„	Low	„	Totally Enclosed Type.
X.	„	„	High	„	„

These classifications alone make up $12 \times 3 \times 10 = 360$ different ratings, and yet it is a very incomplete list for the range of capacities concerned. Such machines would be required at a great number of speeds, differing from the two main groups designated above as Low Speed and High Speed. There is also the rapidly increasing demand for motors suitable for operation throughout wide ranges of speed by shunt regulation, for which more exacting requirement the standard constant-speed motor must be rated somewhat lower (in order to commutate satisfactorily with the weaker field excitation, *i.e.*, at the higher speeds), and must have special field windings. These remarks are merely intended to bring out more clearly the state of development at which the small-motor industry has arrived, and it is scarcely to be wondered at that the large manufacturer, confronted with the task of standardisation, is inclined to demur at the multiplicity of patterns, drawings, dies, gauges, winding forms, insulation moulds, etc., required for securing the best results. He is painfully aware of the already huge accumulation (corresponding, moreover, in large measure to superseded types) already on hand, and is reluctant to admit that the manufacturing of a single line of little machines should assume the proportions of a great department. He has other departments to

consider—for instance, induction motors, alternators, transformers, railway motors, railway generators, lighting generators, and very many more. Only a few years ago he got along very well with but a small equipment. The engineer who proposes to urge the further complications, from the standardising standpoint, which are required in conscientiously applying the knowledge of the subject now-a-days at his disposal, calling for commutators and windings proportioned with due regard to the conditions which should be complied with, has no easy task, and the smaller the machines the more unwelcome are his proposals. While on the one hand it is true that, with small machines, reasonable liberties with the design can be taken without great detriment to the performance of the machine, it is, on the other hand, precisely in the case of such small machines that it should be practicable to produce each different rating in considerable quantities, and hence it should be more economical to work out, with extreme care, such designs as shall, with a minimum of material and labour, yield the best result; and one is inclined to believe that production in quantity should be relied upon ultimately to render negligible the cost of special tools. The writer intends the above remarks to apply to machines of at least 2 H.P. output. For still smaller machines, *i.e.*, for fractions of a horse-power up to one horse-power, the cost is almost entirely a question of careful organisation of the manufacturing processes; almost any first-rate design of motor will serve equally well as a basis, the cost, especially of material, and to a considerable extent also of labour of workmen, disappearing to a far greater extent than in larger machines, in comparison with all the other charges involved before the machine is marketed.

In the other extreme case, namely that of very large units, the contrary conditions prevail, and the engineer's task is a relatively easy one. For these machines, he is encouraged to adopt such an arrangement of the material as shall bring about the most effective result per unit of value, and he readily obtains consent to incorporate, in each successive machine, such changes and improvements as he deems desirable, in spite of the consequently required modifications and often even replacement of extremely expensive patterns, dies, etc.

Even when the manufacturer considers it expedient in machines of from 2 H.P. to 75 H.P. to evolve them, to the detriment of their technical properties, out of a minimum number of drawings, patterns, and dies, the necessities of the special unforeseen cases (which always have and always will continually arise, and which have to be provided for, since they must constitute a considerable percentage of the total business of every progressive concern) will compel the manufacturer, if he is to compete successfully, to depart gradually but inevitably from the original set of standardised designs, and accumulate an irregular, unsatisfactory, entirely haphazard assortment of deviating designs, most of which will be discreditable makeshifts. This result is in striking contrast to that to be obtained by boldly accepting the situation in the first place, making each machine correct for its rating, and, by the employment of all the technical knowledge of the subject available, to look for the profits from the skilful use of a minimum of material and labour in each case. *Then*, when the inevitable necessity arises of supplying special machines, these will be developed from whichever one of a very large variety of *correct* designs most nearly corresponds to the special requirement, and since the design from which the deviation is derived is itself correct, much greater satisfaction and economy will be secured in the special deviating machine. In fact it will far more often occur that, the standard machine having been designed with strict regard to the specified performance, there will be very many special cases where the conditions to be met are considerably different, where the standard machines may nevertheless be used without any change whatsoever.

These are not questions which can be easily decided. The writer realises a little that it would probably be impossible for him, in spite of the best intentions, to consider them from a thoroughly impartial standpoint. As to just how far, he cannot know, but he inclines to the belief that at least a little more regard for technical excellence in the types of machinery treated of in this paper, may perhaps be consistent with the commercial success of the concerns engaged in their manufacture.

DESIGN OF CONTINUOUS-CURRENT DYNAMOS.

By HENRY A. MAVOR, M.I.E.E.

Some years' experience in dealing with the manufacture of Continuous-Current Dynamos has led the writer to seek for a more definite basis of comparison for such machines than has hitherto been available. The value of a trustworthy basis of comparison need not here be insisted upon at any length, but the manufacturer who desires to standardise and systematise the production of his machinery begins at the wrong end if he does not first systematise his methods of design so soon as his experience enables him to do so, and until he has systematised his design the standardising of production must proceed on an unsatisfactory basis. The valuable contributions by the late Professor John Hopkinson and his successors to the literature of the Continuous-Current Dynamo have yet to be developed into a complete theory of the dynamo machine. This paper is intended to be a humble contribution to the systematic treatment of the subject, the object being to put in simple mathematical form certain practical considerations in connection with dynamo design and to use them for the systematic treatment of the subject on practical lines. To do this it is necessary to adopt a few symbols, a list of which is given at the end of the paper.

The parts of the subject proposed to be dealt with are sufficiently indicated in this list, which is alphabetically arranged for convenience of reference. The quantities dealt with are seventeen in number. Certain of these are treated as constants which may be fixed by the designer from the results of his experience; others may be assumed or modified to meet the requirements of the design or of the conditions laid down for the working of the machine; The remainder are derived from members of either or both of these groups.

The dynamo, being a mechanical structure for the transformation of energy, may be considered as consisting of essential and of accidental parts. The essential part is the region occupied by the armature conductors in the magnetic field. This region may be named the "active belt" of the

armature. It is bounded by the peripheral surface of the armature, the surface of the core at the bottom of the slots and the ends of the core. An examination of the machine in terms of the energy generated in this active belt leads to the interesting result that machines of very widely varying size, output, and speed give a remarkably constant value in watts generated per cubic centimetre of active belt at unit velocity in unit field. This constant may be expressed in symbols thus—

K = ergs per second per cubic centimetre at unit velocity in unit field $\times 10^7$

$$= \frac{W}{\pi d l s \times \pi d n \times F} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The value of the constant K must be a compromise between economy in first cost and efficiency in radiation of lost watts. The maximum value of K gives zero electrical efficiency. The maximum possible output of the machine is at half this value. A reduction of the value of the constant K leads to increased quantity of material, increased cost of construction, and increased electrical efficiency. A consideration of the dynamo from this point of view suggests increase in the depth of the active belt, reduction in the watts generated per cubic centimetre and reduction in the depth of the core so as to minimise hysteresis and eddy current losses in the core, with consequent increase in diameter and multiplication of the number of poles. It will be noted that this consideration includes the radiation of all lost energy from the surface of the armature, the value W being the total watts generated by the machine.

It is suggested that members of the Institution may be disposed to contribute to the discussion comparative results on the lines of this paper.

A careful examination of a large variety of types and sizes of machines indicates that the value of the constant K may be taken as showing what may be counted upon as a safe load having regard to the heating conditions. This value the author believes to be about $\frac{5}{10^7}$, or 5 ergs per second per cubic centimetre at unit velocity in unit field.

It is proposed to denominate the value K the Energy Factor of the machine.

Further experience in the use of this constant may reveal the relation between its value and the capital cost of the machine per unit of energy generated. At present it would

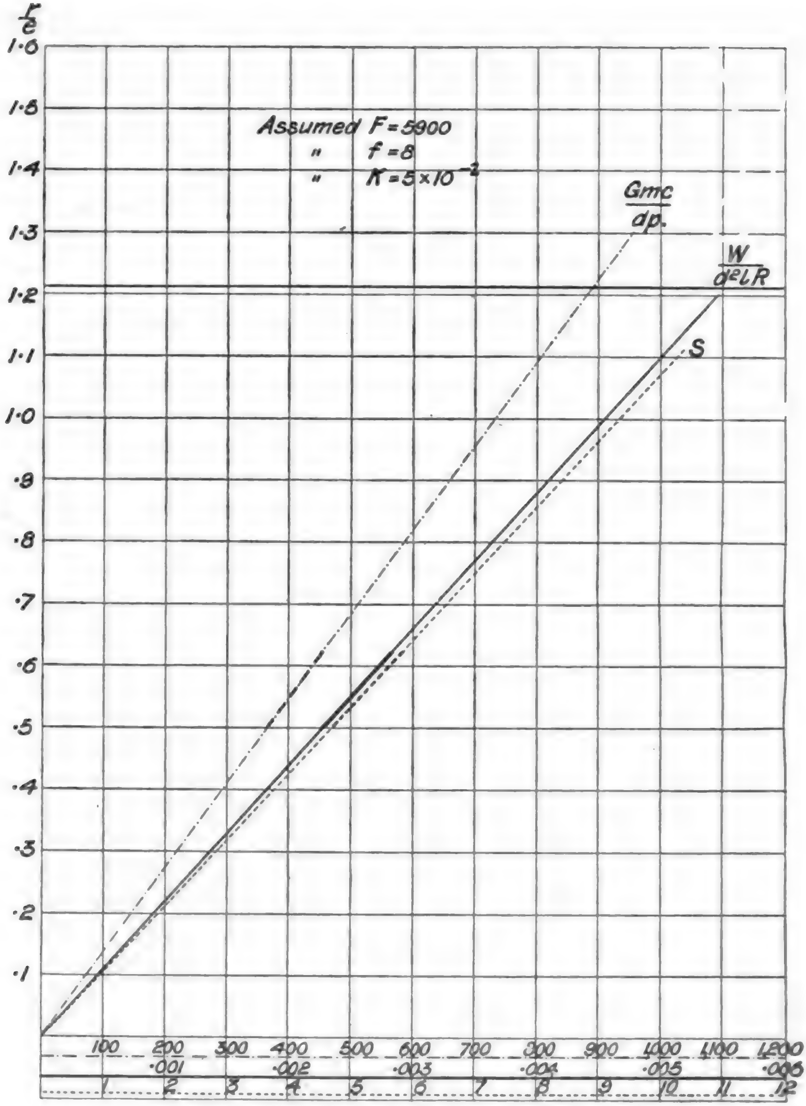

FIG. 1.

appear as though a considerable variation in the energy factor may be permitted without materially affecting the cost per unit of energy generated, and the electrical losses on

many machines bear so small a ratio to the total losses that the free use of ventilation may entirely obscure any disadvantage arising from the increase in the value of the energy factor. At the same time it would appear that, based as it is upon absolute units, it would form a sure standing ground for comparison of the actual performance of machines. The rise in temperature may be so variously estimated and so materially modified by ventilation or otherwise that the indefinite method of comparison on that basis ought to give way to something more sure.

A temperature test, based upon electrical measurements, an electrical and a commercial efficiency test associated with the energy factor and the cost price, would give for the dynamo a more complete basis of scientific and commercial comparison than is now available for any kind of machine.

Many battles have been fought around the question of commutation. The important bearing of the commutating conditions on the satisfactory working of the machine is, of course, thoroughly recognised by all designers.

The most recent summary of this branch of the subject so far as the author is aware is contained in Messrs. Parshall and Hobart's book on "Electric Generators," in which a summary of the theoretical and experimental investigations into armature reaction is given and the relation between the field turns and armature turns is fully discussed, as also the relation between the reactance voltage and electro-motive force generated per section in the armature. It is not the purpose of this paper to enter into a discussion of the points, but rather to embody in a simple form the calculations necessary for determining the conditions which are there accepted as necessary for satisfactory working. The method adopted in the work already referred to is a useful way of dealing with the question, but the methods of calculation adopted are such as to render the consideration of the conditions somewhat complicated. The simplification of these calculations involves very elementary algebra. Assuming a sine wave form for the fluctuations of the current, they may be summarised in the formulæ (2), (3) and (4).

Expressing the total electro-motive force of the machine by

$$E = \frac{2 \pi d l F G n m}{p \times 10^8} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

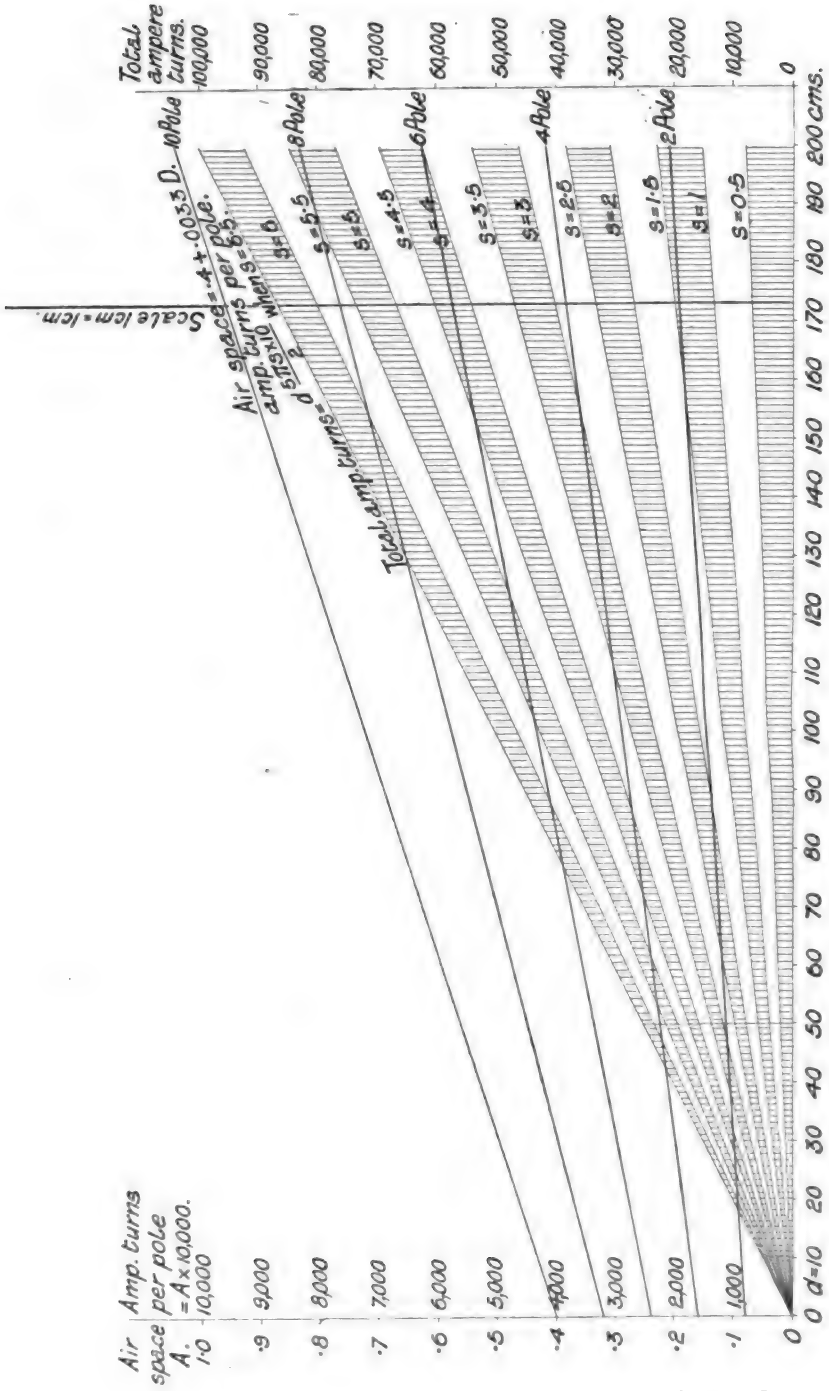
Total ampere turns.
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
10 Pole
8 Pole
6 Pole
4 Pole
2 Pole
Air space = .4 + .0033 D.
amp. turns per pole.
$d\frac{5\pi s \times 10}{2}$ when s = 6.5.
Total amp. turns =
Scale 1cm = 1cm.
s = 6
s = 5.5
s = 5
s = 4.5
s = 4
s = 3.5
s = 3
s = 2.5
s = 2
s = 1.5
s = 1
s = 0.5
Air space A.
Amp. turns per pole = A × 10,000.
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0 d = 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 cms.

FIG. 2.

and the reactance voltage—

$$r = \frac{2\pi \frac{G}{b} n f l b m^2 C}{p \times 10^8} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

we obtain by combining 2 and 3, and cancelling out the common factors, the simple formula—

$$r = \frac{E C f m}{d F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The value of the field, f, due to the current under commutation is probably not so constant as indicated in the work above referred to, but any desired correction may be made upon this factor by introducing the consideration of relation between depth and width of slot or of any other elements which the designer may consider it necessary to introduce. Formula 4 indicates that the reactance voltage is not subject to large modification for any given output. On all large machines the value of $m = 1$. The watts output being given, the reactance voltage is inversely proportional to the diameter of the machine.

Equation No. 4 is true of all machines whether wave or lap wound. It enables us readily to ascertain the value of the electro-motive force of self-induction which has to be overcome in commutation. The electro-motive force available for overcoming it depends, of course, upon the armature reaction, but for this part of the argument it may be assumed that this electro-motive force is made equal to the average electro-motive force generated in the conductors of the armature by their motion through the field.

As we are dealing with the reactance voltage in one section of the armature, we have to deal with the average electro-motive force of the same region.

A section of the armature being defined as the path of the current from commutator to commutator, this average electro-motive force generated in a section of the armature is—

$$e = \frac{2 m l F \pi d n 1}{10^8} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

A distinction must here be introduced between lap wound and wave machines. In lap wound armatures $e =$ the difference of potential between adjacent sections of the commutator; in wave wound armatures the difference of

potential between adjacent sections of the commutator $= \frac{e \times P}{2}$.

It is assumed that the ratio between the two electromotive forces e and r has a very important bearing upon the commutating conditions of the machine. Doubtless the contact resistance of the brushes and their connections and of the connections to the commutator have an important effect upon the value of the reactance voltage, but it is assumed that the values arrived at by the method referred to may with advantage be used in the design of machines. The use of the energy factor considerably simplifies the consideration of the question from this point of view, and makes it easy to plot curves of values of the ratio $\frac{e}{r}$ which will embody the necessary considerations. The value for the total ampere-turns on the armature is derived from equations 1 and 2, and is

$$\frac{G\,m\,C}{p} = \frac{K\,\pi\,d\,s\,10^8}{2} \quad \ldots\ldots \quad (6)$$

and a value for the total ampere-turns per centimetre diameter of the armature in terms of ratio $\frac{e}{r}$ is given by

$$\frac{e}{r} = \frac{d\,F\,p}{f \times G\,m\,C} \quad \ldots\ldots\ldots \quad (7)$$

from 3 and 5.

The relation of the depth of slot to the ratio $\frac{e}{r}$ is shown by

$$\frac{e}{r} = \frac{2\,F}{K\,\pi\,f\,s\ 10^8} \quad \ldots\ldots\ldots \quad (8)$$

which is derived from equations 4 and 5.

The relation of the dimensions and speed of the machine to its output in terms of the ratio $\frac{e}{r}$ are shown by equation No. 9—

$$\frac{e}{r} = \frac{2\,\pi\,F^2}{60\,f\ 10^8} \times \frac{d^2\,l\,R}{W} \quad \ldots\ldots \quad (9)$$

which is derived from No. 1 and No. 8.

These relations may be conveniently plotted in the form

of curves, and for convenience the values are arranged as direct ratios so as to give straight lines.

The diagram showing these curves, Plate I., shows the relations indicated by these equations through a very wide range and the selection of a value for any one of the four quantities, viz., $\frac{e}{r}$=ratio between the average E.M.F. generated between two sections of the commutator and the reactance voltage, $\frac{G\,m\,C}{p}$ = the ampere-turns of the armature, s = the depth of the slot, or $\frac{d^2\,l\,R}{W}$, the ratio between the size and speed of the machine and its output, determines the other three values. They are all interdependent, and the designer can compare his values directly by means of the diagram.

The value chosen for $\frac{e}{r}$ admits of a considerable variation, but there does not appear to be any material advantage to be gained in commutation from increasing its value above 2; and although many machines have been made with as low a value as 1·6, anything below this value appears to be dangerous.

This confines the practical use of the curves within comparatively narrow limits, and would appear to indicate a ready means of systematising designs as regards the values involved in those equations. It will be noted that equation No. 9 leaves indeterminate the relation between diameter and length. It will be seen from equation No. 4 that it is important to keep the diameter of the machine as large as convenient so as to reduce the value of r, in recognition of the importance of not only keeping the ratio between e and r high, but of keeping their positive values low. Further, the diameter of the machine has to be fixed with reference to the value of E, because the number of commutator parts at any given diameter is limited by mechanical considerations. The equations given show further that the relation between diameter and length need not be responsible for the commutating conditions; the machine can be so constructed and wound as to commutate well even though it be small in diameter in proportion to its length.

It has been assumed that the value of the electro-motive force available for overcoming the reactance voltage can be

taken as a definite proportion of the total electro-motive force generated by the armature. This assumes suitable conditions of armature reaction, and it is necessary to make some provision for the accuracy of this assumption. This is done by fixing the number of poles so that the armature reaction bears a suitable relation to the magnetising force of the magnets and is stated in the equation—

$$P = \frac{G\,m\,C}{p \times A \times 10{,}000} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

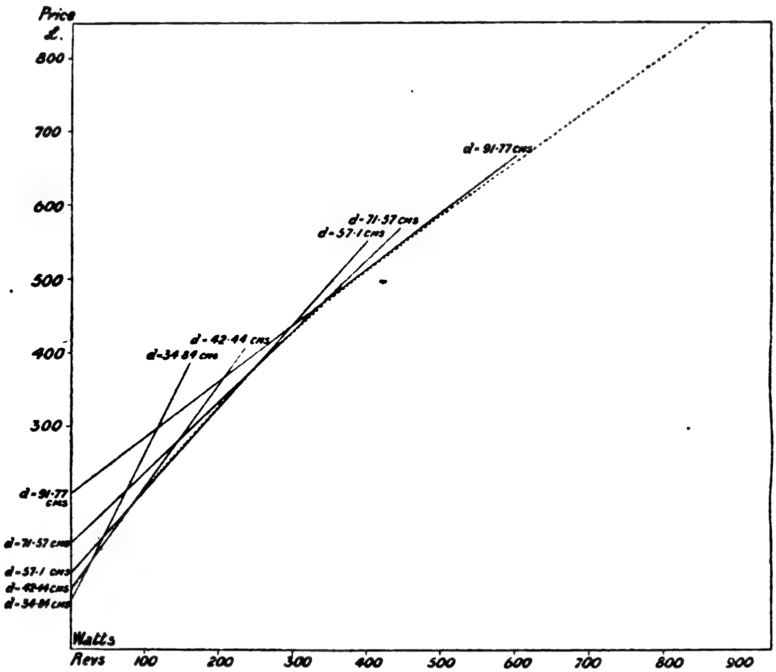

FIG. 3.

i.e., that the ampere-turns on the armature per pole should not exceed 10,000 per centimetre length of the air space. A diagrammatic method of dealing with this part of the problem is indicated on Plate II., in which are plotted values of d as abscissæ, and as ordinates the value of total ampere-turns, ampere-turns per pole and length of air space, the length of the air space being assumed a function of the diameter.

Taking the values of ampere-turns per centimetre of

diameter and depth of slot from Diagram 1, and having fixed the diameter of the machine, the ampere-turns per pole and the number of poles are readily found.

It will be seen that the relation of diameter and length depends not only upon the reactance voltage, but on the number of turns per section and the number of paths through the armature. It will therefore probably be found convenient, in designing machines on the lines indicated, to start operations from the value of m, fixing standard sizes of conductors and the current density to be used in them. $\frac{m\,C}{p}$ is the value of the ampere-turns per section in the armature, and the required current output will give immediately the ratio $\frac{G\,m}{d\,p}$, raising the question of diameter and commutator segments independently of the speed at which the machine is to run.

If the designer proceeds on an assumed peripheral speed, then the diameter is fixed at once and the other quantities fall into line.

To summarise, the values to be determined in the design are disposed of as follows :—

EXAMPLES OF USE OF EQUATIONS.

Constants.	Given.	Assumed.	Found.
f F K	$d\,l\,p$ P	$G\frac{e}{r}E\,m$	s C R r A From (8) (7) (9) (4) (10)
	$d\,l$ P	$p\,m\,E\,c\,r$	s C G R A From (8) (4) (7) (9) (10)
	$d\,l\,p$ P R s	E e	r C m G A From (8) (9) (4) (7) (10)
	$d\,l\,p$ P R s	G e	r E C m A From (8) (9) (4) (4) and (7) (10)
	$d\,l$ R E C	P p G	$\frac{e}{r}$ s m r A From (9) (8) (7) (4) (10)
	$d\,l$ R m	P G E $\frac{e}{r}$	s C p r A From (8) (9) (7) (4) (10)
	R E C	P d G $e\,r$	s m p l A From (8) (4) (7) (9) (10)
	R E C	P m G $e\,r$	s d p l A From (8) (4) (7) (9) (10)

Turning to the consideration of cost, it is found that in the case of many groups of machines there is no regular ratio between the cost and output of the machines, and estimates are difficult to make.

There ought to be such a regular relation, and the following method is suggested for obtaining this result:—

Plotting watts per revolution as abscissæ and costs as ordinates, the position of each machine is marked, and the points representing cost and output for each carcase of a given diameter with varying length are joined by a straight line which is produced to cut the zero ordinate. This point gives the limit of cost to which this carcase approaches as the core length is reduced to zero, and may be called the base cost of any given carcase; the slope of the line drawn through the costs of the machine at different length shows the cost per inch length of "active belt" on that carcase. Increase in diameter increases the base cost and reduces the slope of the line passing through the costs of the actual machines, so that, starting from the smallest diameter and passing to the largest, will give a succession of straight lines, each touching its next lower neighbour at one point, and producing a curve made up of segments of the lines representing each machine, each segment showing the economical range of length for the machine which it represents.

This method will be found useful up to machines of about 100 centimetres diameter.

Beyond this size the cost is very approximately proportional to $d^2 l$ and is not within ordinary working limits seriously affected by the ratio $\frac{d}{l}$.

The diagram No. 3 is an illustration of the method suggested. The ratio between $d^2 l$ the size of the machine, and $\frac{W}{R}$, watts per revolution, is readily ascertained from diagram No. 1 when a value has been chosen for $\frac{e}{r}$ and existing patterns, or new designs can be brought into line in accordance with the costs as shown by the diagram.

SYMBOLS USED IN THIS PAPER.

A = Length of air space in centimetres.

b = The maximum number of sections of commutator covered by the brush.

C = Total armature current in amperes.
d = Diameter of core measured to the middle of the active belt in centimetres.
e = Average E.M.F. generated in one section of the armature in volts.
E = Total E.M.F. generated by armature in volts.
f = Induction field in C.G.S. lines per centimetre length of slot, due to one complete turn.
F = Average flux taken over the whole surface of the armature, in C.G.S. lines per square centimetre.
G = Number of sections in the commutator.
K = Watts generated per cubic centimetre of active belt at unit velocity in unit field (called Energy Factor).
l = Net length of armature core in centimetres.
m = Armature turns per commutator section.
n = Revolutions of armature per second.
P = Number of poles in magnets.
p = Number of paths through armature.
r = Reactance voltage.
s = Depth of slot in centimetres.

$W = E\,C$ = Total watts generated by active belt.
$R = 60\,n$ = Revolutions per minute.

Mr. H. A. Mavor: I wish to express my personal indebtedness to Mr. Hobart for his former work on this subject. This new paper of his will be most useful when one has time to assimilate it. The author has taken up in great detail the very points which are of interest to a dynamo designer, but not in sufficient detail to enable one to design a dynamo from his paper. The great difficulty one finds is, that however elevated one's ideas about standardisation may be, to adhere absolutely to standard is impracticable. It is possible, however, for dynamo designers to adopt a uniform or similar method of comparison of designs. Table 19 of Mr. Hobart's paper relates to a most useful group of machines looked at from that standpoint. It would appear that the introduction of the value of the "energy factor" described in my paper would fill up the gap which exists in this table and make it nearly perfect. A very important point has been raised by Mr. Hobart in speaking of the construction of the commutator. Notwithstanding what we have heard to-day about the obsolete character of continuous currents, there is still a field for ingenuity in the mechanical construction of a commutator which will meet the requirements for more rigid construction. Mr. Mavor.

The limitation of the thickness of the commutator sector in the present method of construction is a distinct disadvantage to the designer. A more simple and rigid method of construction with abolition of the demand for mica insulation would be an improvement. Mica insulation is a bad thing structurally, and if this could be got rid of in favour of a less treacherous substance and a commutator section could be obtained for every turn in the armature, it would be much easier to produce a satisfactory machine. In this particular, as in many others, specifications tying the hands of the designer and manufacturer, and intended

Mr. Mavor. for the protection of the consumer, tend rather to result in the destruction of the design.

Mr. Kapp. Mr. GISBERT KAPP (*Berlin*): The subject of the papers might perhaps be thought old-fashioned, because it concerns continuous currents, but the continuous current has still a large field of usefulness, and it is therefore quite right that we should endeavour to improve the machine which produces it. Mr. Mavor has set himself the difficult task of standardising a thing which has to satisfy very many different conditions. He comes to the conclusion that a deep slot is the right thing. Now, curiously enough, a few days ago a correspondent wrote a letter to the editor of the *Elektrotechnische Zeitschrift* in which he endeavoured to prove that a flat slot is the right thing. Well, I cannot say that my correspondent was wrong; he had another kind of machine in his mind to that of which Mr. Mavor is thinking. When you have to design machines for varying speed, varying output, and, above all, varying pressure, you cannot say that either deep slot or a flat slot is the right thing, but you have to design every case on its own merits. You can easily see that if the machine is to be of moderate size and for 1,000 volts continuous current, which, I suppose, is the limit one would care to go to, that a very deep narrow slot is not the best thing, because you lose too much space for insulation. If, on the other hand, you have to build a railway generator of 1,000 kilowatts, then you can use a deep slot, because you have stout armature bars and the waste of insulation is hardly increased by deepening the slot. Another point which has been touched upon is the difficulty of making commutators. It is, of course, advantageous to use as many sections as possible; but then the sections may get very thin and mechanically weak. To draw them tight by end pressure applied to chamfered rings is objectionable, because liable to cause buckling, especially in long commutators if they get warm. There is, however, a way to prevent buckling by making the sections not radial, but in the shape of a broken line, something like a very open V.

Mr. Mavor's diagram, Fig. 3, is very interesting. It really comes to this: that for each output per unit speed there is a most economical diameter and length of armature. I have never worked out the cost of machines in that way from catalogues, but I think if one did so, one would find that there are some machines which are not designed to the best advantage. When you look at tenders of machines and find one 30 per cent. higher than the others, you will probably see that this machine falls outside Mr. Mavor's curve. Might I, in this connection, be permitted to mention a formula which is very simple and gives the output of a machine, as a function of the armature diameter D, the length of armature L, and the speed U, revolutions per minute. The output in kilowatts is $P = C\left(\frac{D}{100}\right)^2 L\left(\frac{U}{100}\right)$. D and L are given in centimetres. In this formula, C is a coefficient which is very elastic. The reason for this elasticity is obvious. If you have to design a machine for high pressure you lose more in insulation, therefore you must increase the diameter and C will be rather smaller than for a machine built for low pressure. C also varies with the diameter. In a

large machine you do not waste so much space in insulation, and you utilise the material better. Finally, the skill of the designer has also some influence. I find that the coefficient C varies from about 0·6 in a small machine designed by a not very skilful man, to about 2·6 at the highest in a large machine designed by a man of skill. This large variation is unavoidable, because of the influence of so many details. Thus the voltage and heating have some influence quite apart from the dimensions. There was a time when the output of machines was limited by sparking. I think this limit has now been passed, and we are really limited by heating, and the size of the machine will depend upon the heating limit which the consulting engineer chooses to allow. As far as C is dependent upon dimensions I have also attempted to find an expression for it. It is $C = 0{\cdot}6 + \frac{D}{200}$. Because of the influence of the other considerations this formula is only approximate. Thus for a machine of, say, 2 metres diameter of armature, the coefficient would be *only* 1·6, whereas in reality the coefficent may be 2. You see the formula is not accurate, and cannot be accurate. Now the very fact of their being so shows that it is impossible to give the output of the machine merely as a function of its size and speed—that is to say, without due regard to other circumstances, such as the pressure and the heating limit. For the same reason I am a little suspicious of the Mavor curve, as it does not take into account those special conditions which I have mentioned. Perhaps Mr. Mavor will explain in his reply whether this curve is intended for machines of any pressure and any absolute size, or whether it applies to a certain line of machines for a particular pressure. Mr. Kapp.

Professor SILVANUS P. THOMPSON: We are indebted to both the authors of these papers for much extremely suggestive and interesting matter, and I hope if one criticises, it will not be thought that one does not appreciate many of the good things which are to be found on either hand. Professor Thompson.

I have been trying to understand the inner meaning of this "energy-factor" which is introduced to us to-day. I can quite believe that it is a very useful thing to study, in order to compare together the different makes of machines, and certainly that curve which Mr. Mavor has brought out as to the cost of a series of machines, beginning with the one which has a body only, and no soul to do any work, will enable us to study the matter from a new standpoint. But I think that the "energy-factor" so-called must be looked at very carefully. It is, if I understood it rightly, ergs per second per cubic centimetre of active belt, the machine being considered as running with unit velocity in unit field.

If a thing is moving at unit velocity across unit field, every centimetre length of it is generating exactly one hundred millionth part of a volt. Now the power of a machine—the output in watts—is the product of the amperes going through it and the volts that it is generating. Consider a cubic centimetre of this active belt. It is partly made up of copper, partly of insulation, and partly of iron. Take such a unit cube and move it at unit velocity in unit field, and there will

Professor Thompson.

be generated in one direction through it the one hundred millionth part of a volt; and the number of amperes that are going across it, entering through one square centimetre face and going out at the other, when multiplied by that fraction of a volt will be the number of watts generated in it. So, it turns out that this energy-factor is after all simply nothing more than the number of amperes going through a square centimetre of that active belt—copper, insulation and iron all reckoned together. K is simply the nett current-density per square centimetre of the volume of the active belt. Well, that is literally all that the energy-factor means. Now it is not very surprising, if that is the physical meaning of this energy-factor, that different makers have come to somewhere about the same practice for similar machines, for they have somewhere about the same proportion of copper to iron in machines that are built on similar lines, and they also work necessarily to about an equal ampere density at normal output, because they have to get rid of about the same amount of heat per square centimetre of the active surface. That leads me to another point in connection with Mr. Mavor's formula giving dimensions of machines and output. There is a much simpler formula used some years ago, which was first suggested by Mr. Steinmetz. It is this—that the output of a machine in kilowatts is equal to the diameter of the core-body multiplied by the length of the core-body (the length between the core-heads) divided by a constant. That constant, for inch-units, will be somewhere between 2 and 4. It may be even less than 2 in large and well-designed machines: in small machines it may be as great as 4, or even over 4. [Mr. GISBERT KAPP: Where does speed come in?] The speed does not come in, because it is assumed that in any particular type of machines there has been established by experience a certain surface-speed which is best. Volume does not come in, but surface, because for machines of a given efficiency the losses are proportional to the output, and the surface (at a given speed) must be proportional to these losses for equal temperature rise. It is a very good formula for a rough and ready comparative test of designs.

I have been trying to follow the figures given by Mr. Hobart, and again I must express the indebtedness I feel to Mr. Hobart, not only for the paper he has given us to-day, but for his good work in conjunction with Mr. Parshall in furnishing numerous useful data to help us to understand dynamo design and practice. But I wish he would give us a little more to enable us further to assimilate that which we have already got. I want to know, and I hope Mr. Hobart will consent to tell us, something more about some of these machines. It is not easy, without a good deal of time spent upon calculation, to see precisely what they amount to. In the case of the three machines having 100 kilowatts output (on Table No. 2), I do not find the surface speed of the armature. Of course it can be found by working it out. The surface speeds in those machines appear to run somewhere about 4,700 feet per minute. The values of the magnetic fluxes are not given us, neither are the flux densities in the gap given us, so that it is impossible to make anything like approximate estimates of the densities of the field in which the commutation has

taken place. One can only infer it indirectly. Well, we cannot check the results unless one has something of that kind to go by, and one cannot even check the theory that is laid down without having data of that kind. We owe to Mr. Parshall—I suppose to Mr. Hobart too—the particular theory of the commutation of a machine in which the expression "reactance-voltage" occurs; and I notice Mr. Mavor accepts the idea of "reactance voltage" in the same sense in which it has been put forward by Mr. Parshall and Mr. Hobart. I am not going to say it is not a useful step to have some definite term such as the thing called "reactance voltage" to put before one in discussing the question of commutation; but I am not at all satisfied that the quantity we are calling "the reactance voltage" is really the right quantity to be considered in the problem of commutation. Further

Professor Thompson.

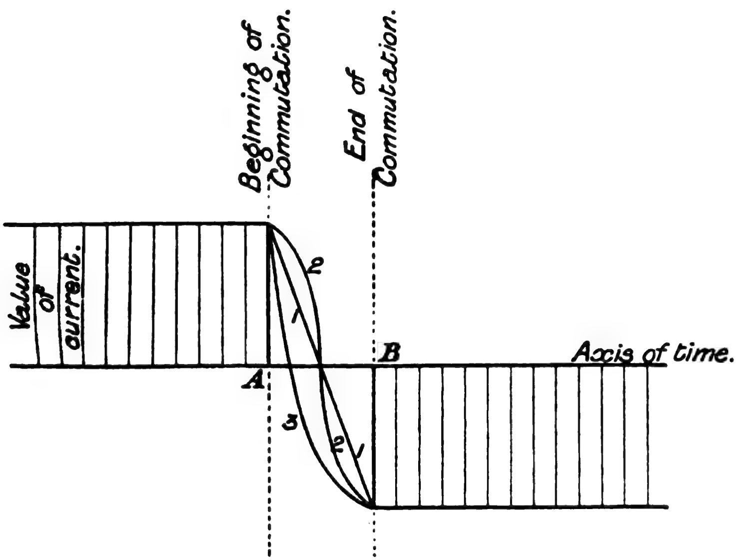

FIG. A.

than that, I do not think it is anything more than a very rough approximation to consider the ratio between what they call reactance voltage and the average voltage per bar of the commutator per element of the winding, because, if I understand it, the act of reversing the current during commutation requires a magnetic field, and the magnetic field which is required for that purpose is not an average field; it is the field of the particular place where the commutation occurs. Now that field is not necessarily by any means the same as the average field under the pole, nor is it necessarily proportionate to it. That depends upon various things—not only on armature reaction, but on the construction of pole-tips, extent of saturation

Professor Thompson.

in different parts of the pole-face, and so forth. Still, in spite of that, it is useful to have that idea of reactance-voltage.

Now think for a moment of the problem of commutation, which we may deal with by aid of a diagram. Take a horizontal line to represent time. We have got, in a certain element of the winding, a current which has to be reversed. The value of that current we may plot vertically upward or downward according to whether the current is in one direction or in the other. Before commutation takes place the current has a uniform value: we have our ordinates all of the same height. There comes a moment when commutation is to begin. Now let us suppose that we have some imaginary kind of brush or arrangement for commutating which did not begin its work gradually but began suddenly. It suddenly short-circuited the loop in question. What we should desire or wish to occur would be that the current in that loop should accurately and suddenly go down to zero, and then should absolutely suddenly reverse itself to an equal value of current in the other direction. The positive ordinate would have to be suddenly changed to an equal negative value. But we cannot have it occur suddenly. It is simply physically impossible. Nature ordains that the operation will last a certain time. Well, we take a certain time, represented on our diagram by the length from A to B. At the end of that time what we desire is that the current shall have grown to an equal but negative value; and that from that point onwards, until the next act of commutation takes place the current shall remain uniform. Now the act of commutation has to take place in that space of time, or while the armature moves through the corresponding length of space on the periphery of the machine. How does the current in fact pass from being of full value in one direction to being of full value in the other direction? Does it fall down gradually to zero, and then gradually grow again in a straight line like that marked 1, 1? Or does it not much more likely take a form more like a curve of cooling, that drops quickly at first and remains almost concave like that marked 3 in the diagram? In the question of how the current dies and grows again everything depends, not only upon the value but on the distribution of that fringe of magnetic field in which the act of commutation takes place. The fringe is never uniform: it is itself distributed unequally. You may have, with different shapes of pole-edge, all sorts of different distributions of the fringe, and therefore different shapes for that connecting curve. You may have all varieties in the form of the curve; and until we know in any type of machine what is the general form of the curve, it will be impossible to know exactly how to apply calculation. I do not believe anybody knows what does happen in that act of commutation. I do not remember that anybody has investigated it experimentally: it is not an easy thing to investigate. Under these circumstances, what Mr. Parshall has said, in print I think, is that any suggestion may be equally good with any other one, and so he takes therefore one which at any rate lends itself to calculation. He assumes that what happens here is like a bit of an alternating current. You have got a current which is going from a positive value to a negative value, and there is the sketch marked 2, 2, of the bit in between. You

assume that it follows a half-period of a sine curve. I do not believe in that top part of the curve at any rate: it is much more probable that the curve falls rapidly at first. Professor Thompson.

Now I have not touched upon the question how far the brushes affect this operation. It is a question how the brushes do their work, and with the use of carbon brushes has come a most valuable feature which is not half appreciated in theory, though it is certainly appreciated in fact—that the contact resistance of the carbon against the commutator segments shears off the current by giving a variable area of contact beneath the brush face, and it helps to shear off that current and to let it grow again in a much more uniform manner than if the resistance were introduced or removed abruptly. Very well, if you use carbon brushes they shear off the current in the loop of winding, as if gradually closing a valve. And on reversal they gradually open a valve for the reversed current. In fact the sliding carbon brush may be likened to a kind of slide valve for the current during its commutation. The resistance in that varying area of contact of the carbon brush plays a very great part in determining the form of that particular curve. With the assumption that its form is that of a piece of a sine curve, you are able to calculate; a sine curve being assumed to have a certain periodicity, which depends upon the width of brush. And then on this periodicity, the self-inductance of the loop, and the amount of current to be reversed, is based that calculation of reactance-voltage. Now I fail to see that we can accept in any kind of final or exact way (though it may serve as a rough approximation) that value of the average electro-motive force per section as being the electromotive force with which to overcome the reactance voltage during the act of commutation. We want to know what is the transient value of the induced electro-motive force in the short-circuited loop where it is, in the fringe of the field; not what its average value would be while the loop is moving under the pole-face; and experiments are badly needed in various types of machines to tell us what is the real true value of the electro-motive force induced in the loop, not the average for the whole surface, but the transient value during the period of commutation when it is passing through the fringe. If we could get at the value from instant to instant the information would be still more valuable.

To me the comparison of ampere-turns on pole and of the armature winding per pole also appears fallacious. Given the density of the flux, the speed and the time of commutation, there must be for a given type of machine a definite number of amperes per inch of periphery of the armature which can be commuted without spark: and that number will be independent of the length of the machine parallel to the shaft and of the number of ampere-turns of excitation required to produce the field. Modern practice in slot-wound generators fixes the limit at about 650 amperes per inch of the armature periphery.

Much has been written on the question of commutation. Much has also been written on the question of the elements of design: one thing has not appeared, either in Mr. Hobart's paper or in Mr. Mavor's paper, nor in a brief and curious little paper recently written by Mr.

Professor Thompson.

Short of the English Electric Company: that is, none of them touch on the question of the engines. It is useless to design dynamos if you cannot find reasonable engines to drive them. It is all very well to ask the engine-builders to build you the engines that will suit your dynamos, but engineers would certainly hesitate to do what Mr. Short asks them to do—to give you a line of engines from very small ones up to very large ones which will vary their speed simply inversely in proportion to their normal rated power. They certainly would not like to do it. The number of revolutions will not go down in exact proportion as the horse-power goes up. Good engine design requires something more like a square-root rule. The whole question of engine design comes vitally into this question of dynamo design, and unless one has the engine speeds properly prescribed for the different sizes and takes them into consideration in the design of the dynamo, that design may be wholly fallacious. There is much more that might be said in detail on Mr. Hobart's paper: there are many useful things—many beautiful things in that investigation by experiment of the distribution of coils. Their details deserve study and consideration. But because they are details I forbear any further remarks.

Mr. Chamen.

Mr. W. A. Chamen: I would only say that I am delighted to learn from Mr. Hobart that we are not to suppose that we shall not be able to continue the use of high-speed dynamos of large size. I think those of you who are going to visit Port Dundas this afternoon will see what will interest you. There are several sets of 1,100 and 1,200 horse-power engines running at a speed of 230 revolutions a minute direct-coupled to various makes of dynamos, and there is one of 2,400 horse-power recently put in running at 180 revolutions a minute—I refer to one of the very largest Willans engines that has yet been built. I have felt for a long time past that the difficulty experienced with commutators in these comparatively high-speed machines of large size has been mechanical; and I only rise to say that experience during the last two and a half years has convinced me that it is so. I think if these mechanical troubles can be got over, as they have been got over to a very large extent with the dynamos you will see this afternoon, there is no reason whatever why we should not go on using the high-speed engine which gives us such a beautifully even turning moment.

Mr. Sayers.

Mr. W. B. Sayers: I am afraid that I am not in a position to discuss either of these papers. I feel that I ought first to read them and to digest them. I will only make two remarks—one refers to the difficulties of standardisation. It is this: if you make a line of machines of different sizes, but all for the same voltage, you have not got a continuous series of machines—each machine will be a new model; the reason being that the restrictions imposed by the requirements for good commutation *naturally* result in there being a voltage proper to each size. If it were practicable to make the voltage suitable to the size of machine, just as the current output and speed are, the difficulties of producing a range of machines of equal merit would be vastly reduced. Of course limitation of the magnitude of reactance-voltage

and of the voltage-difference between adjacent commutator sectors has the same effect when the larger size machines are reached. Mr. Sayers.

The other remark is with regard to commutation. Professor Thompson sketched a diagram illustrating the reversal of current in the armature circuit at the commutation point. Now, to use rather unscientific language, one may say the current knows where it has to start from. It is, say 10, 20, 100 amperes—that is, it is equal to the current in the armature bars at the commencement of the reversal, but it has nothing to lead it up to the proper value until the short-circuited coil is just on the point of being introduced into the armature circuit.

If the curve of change of the current-direction approximates sufficiently nearly to the required one, the effect of the growing resistance at the brush contact acts as a sort of adjustment, and the current in successive coils is brought to the correct value and the coils introduced to the circuit sparklessly; but if the brush has too much to do, commutation is still effected it is true, but the current density in the last narrowing strip of brush contact surface is so great as to cause the carbon to become red-hot, and if there is still a difference between the values of the currents in the short-circuited coil and the armature at the moment when contact between the brush tip and commutator sector ceases, the final adjustment is made at the expense of an arc of greater or smaller dimension and we have sparking.

Col. R. E. CROMPTON: As I arrived at such a late period of the discussion I ought not to have spoken, but as Mr. Mavor sent me an advance proof of his paper, and as I have not only read it but have had several sets of calculations made to see how far recent types of dynamos manufactured by my firm agree with Mr. Mavor's figures, I think he expects me to speak, and I therefore say with much pleasure that I find that Mr. Mavor's ideas are a very valuable contribution to the practical literature of Dynamo Design. Much that has been written on this subject is of no value to us manufacturers, but this is not the case with Mr. Mavor's paper. Colonel Crompton.

Mr. Sayers points out that many of the commutating faults observed in working large dynamo machines are due to a combination of inferior design with insufficient mechanical accuracy of manufacture. This is undoubtedly true. The large diameter of the commutators which now have to be used requires special tools and special design to ensure that the commutating surfaces remain truly cylindrical, and that the segments are held securely in position. One of the tools which has been introduced by those who are most advanced in these matters is the one which I may call the "Artillery Wheel Press" system of holding and compressing the commutator segments into true cylindrical form. This machine consists of a large number of radial plungers worked by hydraulic means (forcing an iron ring inwards so that the metal is actually "upset," and thus the ring, after the plungers are withdrawn, is left permanently smaller in diameter), and was introduced, I think, first in our Royal Arsenal at Woolwich in substitution of the old method of shrinking the iron tyres on to the wooden wheels. This machine, when applied to the compression of com-

Colonel Crompton.

mutator segments, has produced most excellent and permanently accurate commutators which give no trouble from the subsequent displacement of the segments.

The use of this tool is really a substantial advance in dynamo construction, and it is to be noted that as we English constructors have always prided ourselves on being somewhat in advance of our American and German competitors in this one respect of turning out dynamos coupled direct to high-speed engines, we require, even more than they do, absolute perfection in our commutator designs.

Mr. Esson.

Mr. W. B. ESSON (*communicated*): I have read Mr. Mavor's paper, but it has failed to convince me that the introduction into dynamo designing of yet another term is likely to be of much service to us. The paper is extremely interesting as showing the way in which different men set about solving the same problem; but I do not recognise that this "energy-factor" gives us a term of importance, for, after all, Mr. Mavor's formula appears to be but a modification of that given in a paper of mine read ten years ago.[1] The latter formula gave the output of a dynamo as proportional to $D^2 L r$, when D is the diameter of the armature core, L its length, and r the revolutions per minute, and the coefficient, by which these dimensions were multiplied to give the actual output in watts, is the energy-factor if you like to call it so; in our drawing office it is called the output coefficient, and a very good name it is. There is more logic in assuming that the output is proportional to the armature surface than to the cubic contents of the so-called active belt; in fact, I may go so far as to say that there is no rational foundation for expressing the output in terms of the active belt, seeing that for the same heating the output can only be proportional to the square root of the depth of the slot. The $D^2 L$ formula being recognised as expressing very well the output, we should get no advantage by accepting Mr. Mavor's in its place, while, for reasons which I need not go into now, the output coefficient increases with the size of the machine; it does not remain constant as Mr. Mavor would lead us to believe.

Towards the end of his paper Mr. Mavor states that the ampere-turns on the armature per pole should not exceed 10,000 per centimetre length of air-gap. I suppose the author arrived at this figure of 10,000 by experience. It is a usual figure and represents good practice, but I should like to make some observation with regard to it. In my paper already referred to, I used the term "volume" to denote the product of the total number of conductors in the armature and the currents they carried. It was not a particularly well-chosen term, at least Thompson says so, and later he suggested *circumflex* instead. Well, I showed that with a value for the circumflex

$$V = \frac{576\, l\, I}{\phi}\text{*}$$

the forward and cross induction at the pole-tips would be equal, the

[1] *Journal of the Institution of Electrical Engineers*, 1891, vol. 20, part 93, page 265.

* I is the induction in the air-gap in g.c.s. units, l the length of the air-gap and ϕ the angle of the pole-face in degrees.

Mr. Esson.

field being consequently *nil* at the brushes. I recommended as a good working rule that the circumflex should never exceed half of this critical value; then we could always make sure that there would be sufficient field for reversal. For example, according to my formula, the circumflex on a 4-pole armature having a pole angle of 60°, an air-gap of a centimetre, and an induction of 8,400, would be—

$$\frac{288 \times 8,400}{60} = 40,320.$$

The ampere-turns per pole are simply the circumflex divided by the number of poles, and they are therefore 10,080. This figure agrees pretty well with the 10,000 given by Mr. Mavor, but of course he ought to take into consideration the induction and the pole angle.

There appears to be a mistake in equation (10). What Mr. Mavor means to say is, I presume, that the current in each conductor $= \frac{C}{p}$, multiplied into the number of conductors per pole $= \frac{2\,G\,m}{P}$, this product being ampere-turns, should not exceed 10,000 for each centimetre of air-gap, or

$$P = \frac{C}{p} \times \frac{2\,G\,m}{10,000\,A}.$$

The expression $\frac{G\,m\,C}{p}$ for ampere-turns is incorrect, though accidentally it fits a 2-pole machine. The proper expression is $\frac{2\,G\,m}{P} \times \frac{C}{p}$, and incidentally it may be mentioned that with regard to ampere-turns the words "per pole" are superfluous, as by the circumstances of the case, ampere-turns are determined by the number of poles. From this it will be seen that the ampere-turns on a 4-pole dynamo is half what is given by the quantity $\frac{G\,m\,C}{p}$, on a 6-pole one-third, and 8-pole one-fourth, and so on. In addition to the quantity denoted by the term circumflex, I always use the term "ampere-bars per pole" myself, never ampere-turns.

Dealing with Mr. Hobart's dynamos, the 1,600 k.w. machine has an air-gap of 1 centimetre, an induction of 9,900 and a pole angle of 12°. According to my formula the circumflex ought therefore to be 237,600, but in the machine it is actually 348,480, there being 2,640 conductors and 132 amperes in each. This justifies Mr. Hobart's remark that the characteristic of his machines is high armature strength per pole; in fact so high is it that with the 25 per cent. overload the field at the pole-tips is just on the point of being reversed, while with the 50 per cent. momentary overload, according to the formula, it would be actually reversed.

Now this is very interesting, because it shows that in machines in which the armature teeth are highly saturated the *real* air-gap by no means corresponds with the *apparent* air-gap. The latter is the distance between the top of the tooth and the pole shoe, but the former is considerably greater than this, which explains the non-reversal of the field. I am not inclined to follow Mr. Hobart and run my machines so

Mr. Essor. perilously near a critical limit; at the same time it must be admitted that armatures can be loaded up to a much greater extent than would appear possible from the dimensions of the apparent air-gap, and without doing harm. In all probability the magnetic resistance of the cross field is quite 50 per cent. greater than the apparent air-gap and iron parts would account for; it may be even more than that.

It is rarely that a paper presented to the Institution contains so much data as does Mr. Hobart's, and we are under considerable indebtedness to him for the results of his experiments on reactance-voltage. Briefly, the conclusions at which he arrives are, that the difference between the inductance of a coil laid on a smooth core and that of one laid in slots is not so great as might be expected; that the subdivision of the coils, within the limits of practice, has no material effect on the inductance, and that the shape of the slots within the limits of practice has little effect either. These are valuable results, but it appears to me that the condition of good working depends greatly upon the ratio of the reactance-voltage to the average voltage generated per segment not exceeding a certain limit, because the same factors enter into both. There appears to be no definite ratio for this in Mr. Hobart's machines. In the small ones it varies from 1 : 5 to 1 : 2, while in the three large machines from 1 : 2, 1 : 2, and 1 : 2½ respectively. I can well understand Mr. Hobart's summing up the matter in the rule to make the reactance-voltage as low as considerations of economy and efficiency permit, but it is not so clear why the limit should be placed at 5 volts. After all, the field fringe is responsible for the excellence of the commutation, and while the reactance-voltage can be assumed as roughly proportional to the length of the armature, so is the commutating fringe and so also are the volts generated in the machine per segment. It appears then that the terms upon which the average voltage and the reactance-voltage depend all cancel out, with the exception of the current; and this points to the conclusion that there is for armatures with bars lying in slots a limiting value for the current which should not be exceeded. Whenever the output corresponds to a higher current the poles should be increased. I notice that in neither of Mr. Hobart's machines does the current per path exceed 150 amperes, and at this limit no trouble need be apprehended. In Mr. Short's paper recently read before the Manchester Section, he proposed for all sizes of machines 125 amperes per path; but when, as compared with this, we consider machines yielding over 4,000 amperes and having only 16 poles, such as are to be seen in the Berlin Central Station, it will be realised that the designing of the latter is a matter of greater care.

One cannot help sympathising with Mr. Hobart in his plea for designs more carefully adjusted to the conditions under which the machines have to work. Unfortunately, however, every appliance turned out commercially is a compromise between theoretical excellence on the one hand and cheapness of production on the other, and dynamos form no exception to this rule.

Mr. Hobart. Mr. H. M. HOBART: I tried last night Mr. Mavor's formula No. 4 for the reactance-voltage. It worked all right in the case I tried, and it is

many times quicker than the long way round that I have been doing it, and I think it is very useful. Besides, as he states, the terms of his formula show so clearly the relations of the quantities affecting the reactance-voltage, that a comparatively superficial inspection of a machine affords data for forming an opinion as to its commutating properties. It is interesting to note that the periodicity of commutation is eliminated from the formula in the form in which Mr. Mavor gives it. Mr. Hobart.

Mr. Kapp spoke of 1,000 volts as being the limit for commutating dynamos. It is my opinion, since there is now no more trouble from sparking and the flashing over from brush to brush which is in the first instance always caused by sparking, that the difficulties in designing commutating dynamos decrease the higher the voltage, except for the question of insulation where they are of the same nature as with alternating-current machinery. I do not know whether any demand for higher voltage continuous-current dynamos will arise, but so far as I have had occasion to work in this direction, I have found the difficulties, on the whole, to decrease at higher voltages.

Mr. Kapp referred to Mr. Burke's interesting design for a commutator segment for overcoming the difficulties of centrifugal force. That is an excellent way, and there are others that have been patented recently, and by using one or other of these methods I do not see why there need be any further concern, even with long segments, as to the bending of the segment. None of these devices are especially complicated; one of them has an auxiliary dove-tail, and other similar modifications are practicable. Hence high peripheral speeds for commutators ought to be consistent with mechanical solidity. Herr Lasche recently published some very interesting designs of constructions for large alternators, by which they are given sufficient mechanical rigidity by tension members instead of by heavy castings. If this should also prove to be practicable in connection with commutating machinery, it would still further advance the prospects of high-speed direct-connected machines, inasmuch as it would, as in Herr Lasche's alternators, lead to obtaining the requisite stiffness with a much smaller outlay for material not electromagnetically effective.

Dr. Thompson asks for further data of the machines illustrated in Fig. 1. I would say that the peripheral speeds of armature and commutator are given in Table VII. The gap densities for the different cases ranged from 7,000 to 8,000 c.g.s. lines per square centimetre. I do not myself attach importance to the ratio of the reactance-voltage to the average voltage. In fact I have lately altogether discarded considering the average voltage further than to keep it down as much as practicable in order to avoid trouble in such cases as when—after considerable service—the mica may become impregnated, say, with oil. If then the average voltage per segment is high, it does not give rise to the ordinary sparking, but to an incipient leakage which gradually carbonises the surface of the insulation. But as regards ordinary sparking, it is only the reactance-voltage which, in my opinion, is of importance.

Then as regards the magnetic fringe, the commutating zone and

Mr. Hobart. that subject in general, on which Dr. Thompson and Mr. Sayers spoke in a very interesting way. I find that extremely complicated to follow, and have never been able to make much out of it, and I think that success has attended shaping pole corners and modifying the air-gap to improve commutation, only in exceptional cases. I do not now give much attention to these points, but merely make the reactance-voltage so extremely low that so far as relates to sparking it does not make much difference where the brushes stand. I have designed lately a number of machines which carried sparklessly double the rated load, and with the brushes in the geometrical neutral position. This was obtained merely by making the reactance-voltage extremely low.

(*Communicated November 5, 1901.*)—With regard to Mr. Esson's observation that my machines are run "perilously near a critical" limit, I may say that I am of opinion that even very much higher armature strengths are thoroughly consistent with sparkless commutation, when associated, as they may readily be designed to be, with very low reactance-voltage per segment. This will, in my opinion, soon be the prevailing tendency in such designs. It will obviously lead to greater economy in effective material, and I look to at least equal excellence in performance, for, with low reactance-voltage, the regulation may be maintained good by a much less forward position of the brushes than is now customary. Mr. Esson's remarks remind me that at the time of publication of his interesting paper in 1881, I assisted at some tests to see whether the field at the trailing pole-tip was really reversed at the values of the current output which would, from considerations of the air-gap alone, lead to this conclusion. We found this very far indeed from being the case, but the machine was of the projection type with rather highly saturated teeth. Recently, however, I have had occasion to see a machine running with such a high overload of current that there were 20,000 ampere-turns per pole-piece on the armature, and the voltage at this current was lowered to but one-half the normal rated voltage, hence the tooth-density was quite low. Nevertheless, with the brush position the same as for normal running, the commutation was for short intervals—two or three minutes at a time—very satisfactory; of course on longer runs the brushes, not being proportioned for the doubled currents, became hot, and sparking gradually appeared. From observations of various kinds, one is led to doubt how far the unstable magnetic fringe has been of so very much assistance. It is present at no load when not required, but is weakened and moved out of reach in proportion as it could be of use. By designing for sufficiently low reactance-voltage we may dispense entirely with its very unreliable services.

I do not think the dynamo-designer should give much concern to the choice of engine speeds except that in the interests of standardisation, the fewer normal speeds settled upon, the less need be the multiplicity of types. But it is inevitable that the dynamo-designer must meet the requirements for all speeds from slow-speed engines up to high-speed turbines; and for use as motors, his machines are also required to run at some one of a great range of speeds, according to the nature of the work to be performed. From the dynamo-designer's standpoint, one

speed for a given output rarely has such very great advantages over another—*i.e.*, one finds offsetting advantages and disadvantages—and whatever speeds the engine-builders find it of advantage to standardise should be fairly satisfactory to the dynamo-designer, the main consideration being that, to prevent the necessity of standardising a great many machines, the fewer the different speeds called for, the better. The dynamo-designer's task presents less difficulties in this respect than that of the engine-builder. Mr. Hobart.

Mr. H. A. MAVOR: Taking Professor Thompson's remarks first. It is quite true, as he has pointed out, that what I have called the "energy factor" of the machine may be translated into average amperes per square centimetre, but I do not think that affects its use in any way; by whatever name it is called, it remains useful in bringing designs into line for comparison. Mr. Mavor.

With regard to the ratio of reactance-voltage to electro-motive force between commutator segments, I think that the value of considering the difference of potential between segments arises not so much from the direct effect of this value on the commutating conditions, as that in the value of this electro-motive force is included the value of the average field taken over the whole surface of the armature, and the whole matter is tied together in such a way that one certainly must not drop this factor out of consideration, although taking it as a specific value it may not have a direct bearing upon the question.

Turning now to formula No. 4, the important point about this formula is that it enables the designer to ascertain the actual value of the reactance-voltage without the consideration of any extraneous matters; this value being obtained directly from the watts generated by the machine, its diameter, turns per section of the armature, and the average field. Comparative experiments are thus most easily conducted without any complicated calculations. Whatever may be the exact form of the curve expressing the rate of change in the section under commutation, the average value of the reactance-voltage is certainly a most important element in the question.

It is very natural and proper that the discussion on these papers should include the engines for driving dynamos. Hitherto there has been far too little consideration of the connection of the engine and the dynamo. The dynamo maker has designed dynamos to suit the engines of the prominent makers in this country, and that has resulted in many cases in the dynamos being inferior to what they would have been if designed on their own merits and for their own requirements. I think it is not too much for the dynamo maker to ask now that the engine maker should take his turn in designing engines to drive dynamos. One broad fact comes out quite clearly in designing large machines. A good machine is big in diameter. Large diameter involves low speed of rotation, and therefore generators which are to drive large dynamos direct must be of slow speed.

In answer to Mr. Kapp's question about diagram No. 3, it of course must be made for each group of machines for each voltage, but in machines of upwards of 50- or 60-h.p. the voltage does not seem to affect the cost materially.

The President.

The PRESIDENT : I will ask you to accord to the two authors whose papers have just been read, and which have produced such excellent discussions, a very hearty vote of thanks.

The vote was passed by acclamation.

The PRESIDENT : I have now to propose for your approval two resolutions. The first is : "That the cordial thanks of members of Section 9 of the International Engineering Congress, held at Glasgow, be given to Dr. Caird and the Committee of the Congress, and to Mr. Cormack, the General Secretary, for the admirable arrangements made both for the comfort and convenience of the members." I have no doubt you will carry that by acclamation.

The vote was carried unanimously.

The President.

The PRESIDENT : Then, as you are aware, this section of the Congress is composed largely of members of the Institution of Electrical Engineers, and I have therefore to propose the following resolution : "That the best thanks of the Institution of Electrical Engineers be given to the University of Glasgow and to Professor Gray for their kind permission to use the room of the Natural Philosophy Theatre of the University for the present extraordinary meetings of the Institution." That, gentlemen, I will ask you to carry in a similar manner.

The vote of thanks was carried by acclamation.

Professor Jamieson.

Professor JAMIESON : I have much pleasure in proposing a vote of thanks to our President, Mr. Langdon, for the admirable way in which he has conducted our proceedings.

This was carried by acclamation.

The PRESIDENT : I thank you very much for the kind manner in which you have received Professor Jamieson's remarks. It has been a great pleasure to me to attend here. We have had a most attentive audience ; no one could desire a more attentive or considerate one.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

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The Three Hundred and Sixty-sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening November 21, 1901—Mr. WILLIAM E. LANGDON, President, in the Chair.

The minutes of the Annual General Meeting, held on Thursday, May 30th, and of the Extraordinary General Meetings held at the International Engineering Congress at Glasgow on Tuesday, Wednesday, and Thursday, September 3rd, 4th, and 5th, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members :—

Wilfred H. Everett.
W. Murray Morrison.
S. Richardson.

From the class of Associates to that of Members :—

Joseph H. D. Brearley.
C. F. Jenkin.
E. G. Okell.

From the class of Associates to that of Associate Members :—

H. Bingham.
C. D. Burnet.
W. P. Digby.
S. E. T. Ewing.
J. W. Flower.
A. H. M. Francis.
F. W. Joll.
P. C. Middleton.
W. H. Miller.

From the class of Students to that of Associates :—

E. L. Hocking.	P. J. Robinson.
J. Kingston.	S. R. Roget.
Theodore A. Locke.	J. J. F. Shoolbred.
G. Morrison.	A. S. Wilson.

Donations to the *Library* were announced as having been received since the last meeting from Mr. E. Arnold, The Astronomer Royal, Herr J. A. Barth, Cambridge University Press, Messrs. Cassell & Co., Director-General Indian Government Telegraphs, General Electric Company of America, Mons. C. Naud, Mons. A. E. R. Collette, Mr. L. W. de Grave, Mr. L. M. Waterhouse, General Webber, and Dr. H. Wilde ; to the *Building Fund* from Messrs. W. J. Bishop, G. F. Moller, A. J. Cridge, J. A. Seager, F. H. Webb, O. V. Thomas, H. E. M. Kensit, G. E. V. Thomas, F. W. Clements, A. J. Wray, L. Drugman, R. C. Quin, and T. Cushing; and to the *Benevolent Fund* from Messrs. W. J. Bishop, F. H. Webb, R. W. Weekes, and J. P. Lawrence ; to whom the thanks of the meeting were duly accorded.

The President : You will of course be aware that during the recess two eminent personages have passed away from amongst us ; the first in the person of the Dowager Empress Frederick of Germany, who after a very long and painful illness, borne with the greatest fortitude, has succumbed to her disease ; and in the next place of the President of the United States, foully assassinated at a moment when he was endeavouring to afford pleasure to everybody around him. On each of these occasions, which occurred during the recess, letters of condolence have been addressed, in the first instance, to the Home Secretary for presentation to His Majesty, and in the next place to the German Ambassador to be presented to His Imperial Majesty the Emperor William of Germany; and with respect to the late Mr. McKinley to Mr. Choate, the American Ambassador in London. It was thought that Mr. McKinley might happily perhaps survive the attack which had been made upon him. Unfortunately that was not to be. On his demise a further letter was addressed to Mr. Choate, expressing the regret and sympathy of the members of this Institution with the loss which the American nation had sustained by his death. I should also mention that I telegraphed to the President of the American Institute of Electrical Engineers, conveying to him the sympathy of the members of this Institution at the loss which they, in common with the American nation, had sustained in the loss of Mr. McKinley. I will ask the Secretary to read the several letters referred to.

The Secretary read the following letters :—

"Institution of Electrical Engineers,
"28, Victoria Street, Westminster, S.W.
"*August 8th*, 1901.

"To the Rt. Hon. the Home Secretary,
Home Office, S.W.

"Sir,—In the name of the Institution of Electrical Engineers, I

have the honour to beg you to convey to His Majesty the King this expression of our deep sorrow at the inexpressible loss which His Majesty, and indeed the whole world, has suffered by the death of His Majesty's lamented Sister, the late German Empress, whose gentleness and goodness, and whose brave endurance of pain and bereavement, have ever caused her to be held in love and admiration by the people of her Fatherland.

"I beg you also to lay before His Majesty the humble and dutiful expression of our heartfelt sympathy with His Majesty and the other Members of the Royal Family in their great grief.

"I have the honour to be, Sir,
"Your most obedient Servant,
"(Sgd.) WILLIAM EDWARD LANGDON,
"President."

"HOME OFFICE, WHITEHALL,
"*September 9th*, 1901.

"SIR,—I have had the honour to lay before the King the loyal and dutiful Message of the Institution of Electrical Engineers, expressing condolence with His Majesty and the Royal Family on the death of Her Imperial Majesty the Dowager Empress Frederick of Germany; and I have to inform you that His Majesty was pleased to receive the same very graciously.

"I am, Sir,
"Your obedient Servant,
(Sgd.) "CHAS. T. RITCHIE.

"The President of the Institution of
Electrical Engineers,
"Victoria Mansions,
"28, Victoria Street, S.W."

"INSTITUTION OF ELECTRICAL ENGINEERS,
"28, Victoria Street, Westminster, S.W.
"*August 8th*, 1901.

"To His Excellency the German Ambassador,
"9, Carlton House Terrace, S.W.

"SIR,—In the name of the Institution of Electrical Engineers, which, on the occasion of its recent visit, has enjoyed such great hospitality in Germany, I have the honour to beg that you will be so good as to convey to His Imperial Majesty the German Emperor this expression of our most profound regret at the irreparable loss which His Majesty and the Imperial Family, together with the world at large, has suffered by the lamented death of the Empress Victoria, whose

high personal character and rare accomplishments have caused her to be ever held in love and reverence by the country of her birth, as well as by the land of her adoption.

"The Institution begs to offer His Imperial Majesty the assurance of its profound sympathy in his great affliction.

"I have the honour to be, Sir,
"Your most obedient Servant,
"(Sgd.) W. E. LANGDON.
"President."

"Count P. Metternich, German Minister on Special Mission at the Court of St. James's, presents his compliments to the President of the Institution of Electrical Engineers, and, with reference to his letter of the 8th ultimo, is commanded and has the honour to convey to him and to the Institution His Majesty the Emperor's thanks for the expression of condolence, couched in sympathetic terms, on the occasion of the death of Her Majesty the Empress Frederick.

"German Embassy, London,
"*September* 14*th*, 1901."

"INSTITUTION OF ELECTRICAL ENGINEERS,
"28, Victoria Street, Westminster, S.W.
"*September* 11*th*, 1901.

"The Honourable Joseph H. Choate,
"1, Carlton House Terrace, S.W.

"SIR,—In the name of the Institution of Electrical Engineers I beg that you will be good enough to cause to be conveyed to the President and the people of the United States of America, the deep feeling of horror and disgust with which the dastardly attempt on the life of the President has inspired every member of the Institution.

"We desire to tender to Mrs. McKinley, and to yourself as the representative in this country of the United States, our respectful and heartfelt sympathy in this hour of distress.

"We cherish the hope—stimulated by the later bulletins—that your President's life may still be spared; that the Almighty may vouchsafe to him yet many years in which to watch over the destinies of that great people which he has tended with so much loving care and judgment for so long a period.

"I have the honour to subscribe myself, Sir,
"Your obedient Servant,
"(Sgd.) WILLIAM EDWARD LANGDON,
"President."

[*Copy of Telegram received.*]

"AMERICAN EMBASSY SERVICE,
Sept. 13*th*, 1901.

"To the President,
"The Institution of Electrical Engineers,
"28, Victoria Street, London.

"I thank you and the Institution of Electrical Engineers for expressions of sympathy conveyed in their letter of 11th instant, which I have forwarded to my Government.

"CHOATE,
"Ambassador."

"INSTITUTION OF ELECTRICAL ENGINEERS,
"28, Victoria Street, Westminster, S.W.
"*September* 18*th*, 1901.

"The Honourable Joseph H. Choate,
"1, Carlton House Terrace, S.W.

"SIR,—But a few days since it was my mournful privilege to convey to you the expression of horror which filled the breasts of the members of the Institution of Electrical Engineers at the diabolical attempt on your President's life; and to ask you to cause to be conveyed to him, Mrs. McKinley, and the people of the United States of America, the sympathy of the members of this Institution, combined with the hope that God might spare to your country the life of one so justly honoured and beloved.

"Alas! it is now my duty to endeavour to convey to you the intense feeling of regret that a life so valued should have been so sacrificed. In our abhorrence of this crime, which has stricken a benignant lady to the ground, cast a nation into grief, and robbed the world of one of its most eminent men, our pulse beats in unison with that of your nation; and I beg, Sir, that this further expression of the sentiments of the members of this Institution may be conveyed to your President.

"We pray that God may support Mrs. McKinley in this her great grief.

"I have the honour to be, Sir,
"Your obedient Servant,
"(Sgd.) W. E. LANGDON,
"President."

"AMERICAN EMBASSY, LONDON.
"*September* 23*rd*, 1901.

"SIR,—I have received with heartfelt gratitude the kind expression of condolence and sympathy at the death of President McKinley which you have forwarded to me on behalf of the members of the Institution of Electrical Engineers.

"I shall duly advise my Government of its receipt, and it will be

highly appreciated by them and by Mrs. McKinley. Your kind message and hundreds of other similar communications from all parts of the British Dominions, carry an assurance of national friendship and good-will which will be most welcome to the American people.

"Yours sincerely,
(Sgd.) "JOSEPH H. CHOATE.

"W. Langdon, Esq.,
"President."

[*Copy of Telegram to the President of the American Institute of Electrical Engineers.*]

"*September* 18, 1901.

"Members Institution Electrical Engineers, London, tender sincere sympathy yourselves and American nation in sad death President McKinley."

The PRESIDENT: Members will, I daresay, be aware that during the recess the Ninth Jubilee celebration of the University of Glasgow was held. Delegates were appointed from the various learned and scientific societies to attend that Jubilee, and on this occasion, in common with the course pursued by many other societies and institutions, an address was presented by this Institution. Our time will be so much occupied this evening that I will not read it as was intended. Members who are interested will find a photograph of it on the table. The address, which was very beautifully illuminated, was exhibited during the International Congress, and elicited a great deal of admiration.

[*Copy of Address to the University of Glasgow.*]

"TO THE CHANCELLOR AND SENATE OF THE UNIVERSITY OF GLASGOW.

"The Council of the Institution of Electrical Engineers has the honour to convey to the Chancellor and Senate of the University of Glasgow an expression of its gratification at having been invited to participate in the celebration of the Ninth Jubilee of that Ancient Foundation.

"The Council gladly avails itself of the opportunity thus afforded of testifying to the great debt that the Electrical Profession and Industry owe to the justly notorious teaching which many men distinguished in electrical science have received within the University walls. In addition to the wise facilities which the University offers to students in electricity, a great attraction has been the prominent personality and world-wide reputation of the Lord Kelvin, who for so many years occupied the Chair of Natural Philosophy, and whom this Institution is proud to number among those who have passed its Presidential Chair.

"For its aid to the development of submarine telegraphy, for numerous measuring instruments of precision, and above all, for the eminent men whom the University has sent into the field of electrical industry, the Institution tenders its thanks and congratulations; and the Council desires to add the sincere wish that the motto of the City of Glasgow will continue to be applicable to its celebrated seat of learning—

"'LET GLASGOW FLOURISH.'

"Given under our hand and seal this XXVIIth day of August, MDCCCCI.

(Sgd.) "W. LANGDON, President.
"ROBERT KAYE GRAY, Member of Council.
"WALTER G. MCMILLAN, Secretary."

I regret, gentlemen, to have to announce to you the death of Mr. Bristow, who has for very many years, as you know, acted as our Honorary Solicitor. He has afforded the Institution on many occasions the most valuable aid, from time to time assisting us in the reorganisation of the rules, regulations, and principles of the Institution. We all sadly regret that he should have been taken away from us, and I am sure in that we shall have your sympathy. The Council have this evening passed a resolution conveying their deep regret and sympathy to his relatives.

There is one other matter to which I wish to refer, the intimation of which I am sure will be very agreeable to the members of this Institution. It is with unbounded pleasure that I refer to the title which has been conferred upon Colonel Crompton, your Past-President, who has taken so much interest in the Electrical Engineer Volunteer movement. Colonel Crompton, in recognition of services rendered in South Africa, has had the dignity of the Honourable Order of Commander of the Bath conferred upon him. We all rejoice that Colonel Crompton has received that recognition of his services.

No doubt, gentlemen, you will have observed that a certain modification in the order of our procedure has taken place this evening. On previous occasions it has been the custom for the outgoing President, if I may so refer to him, to occupy the chair in the first instance at the first meeting of the session, and after certain business has been transacted to induct into the chair the new President. On this occasion, as you see, I have immediately on entering this room assumed the position to which you have so graciously appointed me. That proceeding is no doubt more in accordance with the fitness of things, because really the new President and the new officers carry on the duties of their office from the conclusion of the annual General Meeting. But, gentlemen, it has this disadvantage attached to it: it deprives the general body of members of the opportunity of testifying to the outgoing President their appreciation of the manner in which he has dealt with the duties which have devolved upon him. I am sure, gentlemen, that no one could have dealt with those duties more fully, more thoroughly, more devotedly than has Professor Perry. In office and out of office,

whatever might be the condition or whatever might be the demands made upon his time—and we know that he has many demands upon his time—he has always been at his post, and I do not think he has ever missed an ordinary general meeting, or if so it was only on one occasion, when I think he was in attendance upon the obsequies of Professor Fitzgerald. I have asked Professor Perry to be good enough on this occasion to present the premiums to those gentlemen who have been nominated by the Council for the reception of awards for the past session, and he has very kindly undertaken that duty. I have now very much pleasure in calling on Professor Perry to present those awards.

Professor JOHN PERRY: The Council has awarded the following premiums for papers, etc.:—

The Council has made a self-denying ordinance. The Council awarded the premiums, and they said, "the most valuable papers read during the session were probably by members of Council, but we will not give a prize to any one of them." Therefore no member of Council's name is found on this list.

Professor Perry presented the awards as follows:—

The "Institution Premium," value £25, to Mr. M. O'Gorman, Member.

The "Paris Electrical Exhibition Premium," value £10, to Mr. W. Duddell, Associate Member.

The "Fahie Premium," value £10, to Mr. A. C. Eborall, Member.

An Extra Premium, value £10, to Mr. J. S. Highfield, Member.

Four Extra Premiums, value £5 each, respectively to Mr. M. B. Field, Member; Mr. W. Wyld, Associate Member; Mr. G. Ralph, Associate Member; and Mr. F. Holden, Member.

The First "Students' Premium," value £10, to Mr. C. B. Nixon, Student.

The Second "Students' Premium," value £5, to Mr. F. J. Hiss, jun., Student.

The Third "Students' Premium," value £5, to Mr. T. H. Vigor, Student.

An extra "Students' Premium," value £3, to Mr. J. H. West, Student.

Two Salomons Scholarships, value £50 each, one to Mr. Joseph D. Griffin, of the Central Technical College, and one to Mr. Herbert Ashlin Skelton, of King's College.

One David Hughes Scholarship, value £50, to Mr. Cyril John Hopkins, of the Central Technical College.

INAUGURAL ADDRESS.

By WILLIAM LANGDON, President.

During no period in the history of this country has commerce expanded, or the Arts, Science, and Literature made such rapid progress, as during the past century, and especially so during the latter portion of that period. For the reason we have not far to seek. Scarcely can a country's commerce advance, nor can trade flourish, without means of communication. Rob us at one fell stroke of our railways, our steamboats, our telegraphs. Conceive the position! Yet, during a great portion of this period such was the condition under which the trade and commerce of the country was conducted.

With the advent of railways there sprang into existence a new life. A new era dawned, not only upon England, but upon the whole world. Intercourse was facilitated; energies were stimulated, and ideas more readily disseminated. Men no longer lived the humdrum life limited to the road wagon or the stage coach. Big potentialities loomed in the distance, and men's minds rose to meet it. Manufacture and commerce grew, and England became more than ever the great engineering and commercial centre of the world.

Whether animated by those stirring events which accompanied the advent of railways, or not, their establishment was soon followed by the production of the need of the moment, a means of communication still more rapid—that first great application of electrical science, the electric telegraph, which, coming as a handmaid to the railways, was shortly to link together every land and people. 1850 saw England and the continent of Europe joined. 1860 hailed the completion of that great enterprise which bound together in bonds of brotherly enterprise and unity—never, we hope, to be severed—the Mother-country and the great continent of North America.

Gentlemen, who shall venture to estimate the value of these two great inventions, these great processes by which the commerce of the world was electrified into new life; by which nations were brought within touch and speech of one another! Who shall say how powerful they have

proved as factors of peace between the peoples of the earth, or determine their effect on civilisation and the moral and material welfare of mankind!

To them, to their authors, England owes much of that greatness of which she may be justly proud; but, richly as they contributed towards the advancement of the world at large, deep as must ever be our debt to them and to those who have worked with them, we do not forget there are others, whose brilliant achievements, if not at present so far-reaching in their beneficence, have greatly added to the lustre of the past period. We, with our feet on the threshold of this new century, would be ungenerous, nay unjust, did we not recognise this fact and pay tribute to those other great discoveries which so brilliantly mark electrical progress during the latter portion of that period.

The telephone! Electric lighting! Wireless telegraphy! The various applications of electricity to chemistry and metallurgy! That great boon to suffering humanity, the discovery of the Röntgen rays, by which the surgeon is enabled to locate by the eye many of those internal derangements of the human frame which hitherto had to be found by more tedious means, and oft with pain and suffering to the patient. And lastly, but by no means the least, that outcome of Faraday's brilliant discovery of the relationship between the electric current and magnetism—the dynamo. As with wireless telegraphy, so with all these great discoveries, each marking a solid advance in Electrical Science, it is possible, nay, even probable, that we are still only treading on the fringe of something greater to follow.

It is such events as these that raise the tone of a nation; that make men feel there is something higher and greater than the possession of wealth for which to work. Emblazoned on the annals of that period are names of which we, as Englishmen, may well feel proud—James Watt, Faraday, the Stephensons, Cooke, Wheatstone, Bright, Kelvin, Siemens, Swan, Wilde. Need I mention to you names—these and many others, labourers in the field of electrical science. Names ever in your mind. Names recorded in history. Names that will never die! From them we of this century have reaped a rich inheritance. Great is their claim on our gratitude: great our debt to them.

It is impossible to look back upon that period to which I have referred—to those great and brilliant achievements which mark especially the latter portion of it, without associating with it, and with them, the name of England's greatest Queen. The Victorian era will ever shine forth as a lustrous jewel in the history of the world. During no previous reign has art and science so progressed, has civilisation and the amenities of life been so richly endowed, or the ties of love and kinship between the Motherland and her Colonies been so worthily recognised, and so happily cemented, as under the benign influence of that life, so pure, so dignified, so devoted to the duties of her exalted state, given to the nation in the person of the nation's venerated Queen.

Impossible as it is to over-estimate the influence which such a life has exercised over the nation's progress, happy are we as a nation in the knowledge that she who has thus left her name engraven not only in history, but in the hearts of her people, is followed by one whose devotion to the welfare, the advancement, and the interests of that vast community over whom he has been called to reign is in every way worthy of the great and brilliant example of her whose life he so nobly seeks to emulate. Gentlemen, our prayer is that King Edward VII. may long be spared to thus watch over the interests of the peoples of his great Empire, to promote the accomplishment of even greater achievements, greater ameliorations of life than those associated with that glorious era which has marked the passing of the past century; that, as the reign of his beloved mother will ever be characterised as that of England's greatest Queen, so his may prove to be that of England's greatest King.

The past stands before us hallowed by the magnificence of the work accomplished. To us it is the gift of a century to improve: still to advance. Competition in every path of life day by day grows keener. How to facilitate our movements; how to economise time; how to crowd the work of two days into one; to be present in all places at one and the same time; to cheapen production; to smooth the rough corner-stones of life—are questions ever seeking aid at the hands of the engineer and the chemist.

Clamouring for attention, three subjects present themselves for urgent consideration :—

The overcrowding of our cities.
The advantages of electric traction.
The economical distribution of electrical energy.

Turn we first to :—

Locomotion in our Towns and Bye-ways.

Writ large in the history of the past century will be the influence which steam has exercised in the progressive advancement of civilised life. Much, however, as the world has benefited by steam, greater still may we anticipate will be the benefits to be derived from electricity. The establishment of railways changed the face of the country. Towns sprang into existence where none existed before. Villages became important centres. Factories and stores gathered around them. Population increased, and with its increase has come that congested condition of life which, unless speedily relieved, is destined to form one of the most serious questions of our time. Well may we ask what is to be the effect of electricity on this? Is this centralisation of life, with all its evil consequences, to find redress in that electric service which is now being established in and around so many of our larger and more populous towns. Are we to look to it to again alter the conditions of life, create new suburbs, and carry into the rural districts some of those advantages which attended the establishment of railways?

No one can look around and remain insensible to the fact that our present mode of locomotion is destined in the near future to undergo great modifications. Our railways are becoming congested; the streets of our chief towns are year by year becoming more than ever blocked with traffic. Will the electric tramway deliver us from the latter difficulty? It is very doubtful. One would say the streets of Glasgow were made for the electric tramcar, yet there are times when even there congestion is rife. What will it be in towns where the streets have not been laid out with that

liberal regard to space which characterises the streets of that great city?

The question we have to approach is one of enormous magnitude. It is not merely one of business, or one of interest from an electrical point of view, but one which, inasmuch as it affects the moral and physical welfare of a great portion of the community, must sooner or later affect our national welfare. We have not merely to consider the means of ingress and egress of that population which is at present residential beyond the boundaries of the chief towns, but that greatly larger body, the pent-up worker, who exists between the factory, whence he earns his bread, and the crowded street, the slum court, or confined alley. To afford them the means of living in a healthful atmosphere, beyond the precincts of the town, means something far beyond any present provision, or the aid to be derived from shallow subway tramcar services; and yet to its accomplishment must we look if the moral and physical advancement we aim at is to be achieved. Year by year the difficulties consequent upon concentration of population become more apparent, and there exists no large town which would not welcome a more rapid mode of transit between its centre and its boundaries. How this is to be best accomplished is a question that must shortly call for grave and careful consideration, and especially so in this great City of London.

The electric tramcar—those moving palaces of light—has come to stay; but its field in the larger towns will doubtless be local traffic only, and with that it will scarcely cope. Traffic between the city and the more distant residential districts will require to be supplemented by a more direct, more rapid, and more extensive means of transit. If these surmisings are correct, and I believe I shall carry you with me in my conclusions, the relief we seek will, in respect of the larger towns, resolve itself into short suburban lines of railway radiating from one or more centres into the suburban districts, supplemented by a tramway service both in the city and in the suburban district.

This it appears to me will prove the solution of the impending changes associated with city life locomotion, and in it will, I believe, be found the means of affording the pent-up population, growing more dense each year, that

relief which is felt to be so necessary for the moral, social and sanitary condition of the people.

But the question is one which goes far beyond the needs of city locomotion. Is it to the interest of the community that this ready means of communication should be limited to city or local areas? Have we not in it a means of supplementing the utility of our railway system, so that not only may populous villages be provided with easy and comparatively rapid means of access between each other and the neighbouring town, but also with the near railway station? It will be evident that to afford these facilities to rural districts alone would prove unremunerative. The point for consideration, then, is how can both municipal area and rural district be so served as to become a pecuniary success of such a character as to extend, as population increases, its advantages farther afield. There can be no question of pecuniary success accompanying the service of the town and its suburban area, but will this accomplish that full benefit desired? Even the suburban district of a town is by no means a fixture. As population increases, as districts become populated, as property increases in value, provided convenience for locomotion is established, so will the man of small means find it to his interest to go farther afield—even to adjacent villages. To afford free intercourse between town and village it is apparently desirable that the limitation imposed upon this means of communication should be restricted neither by boundary of town nor county, but that the basis of its extent and operations should be as nearly analogous as possible to that of the railway system. How this can best be accomplished, whether by joint enterprise, as with the railways, or by county or municipal enterprise, is a question which demands careful and far-seeing consideration. The convenience which a well conducted service is calculated to afford may be, to some extent, gauged by the announcement made on the occasion of the opening of the Southall extension of the London United Electric Tramways Company, to the effect that during the previous three months between eight and nine million passengers had been conveyed over the 7½ miles of electric route, then completed, at fares which did not amount on an average to a halfpenny a mile. To effect the common weal we must carry, to the farthest point remune-

ratively possible, the advantages which attach to this means of communication. By it will the resources of the provinces be more fully developed, and to the cottager be brought some of the advantages of the neighbouring town.

As one associated with our railway system, I ask myself in what way is this service destined to affect existing railway interests. The question is an important and a difficult one. In some instances, as has been the case with the Dublin, Wicklow and Wexford Railway, it will undoubtedly make its mark on the railway revenue. In residential and in pleasure districts it will be most emphasised; but, on the other hand, there is reason to believe that, in many districts, it will ultimately bring to the railways as many passengers as, in other respects, it takes from them. With increased facilities for intercourse will come the growth of local industries; the desire to see what others are doing; to keep abreast of competitors; to see the world. Trade and a love of travel will be stimulated by the facilities with which it is nourished.

I next turn to—

Electric Traction on Railways.

Is electric traction, which is being so rapidly developed in towns, to prove of service to our railway systems?

With the economies which might be fairly anticipated, were our main lines of railway operated by electrical energy instead of by numerous steam units as at present, I have, to some extent, dealt previously. To many it will, I daresay, appear that the economies which I then set forth might properly have been extended. In this I agree, and I equally agree that there may have been charges on the other side which I failed to take into account. Of this, however, I think we must all be aware, that if it were possible to convert the existing systems into electrically worked systems great advantages should accrue. The conservation of our coal; the greater purification of the atmosphere; the increased cleanliness of all things forming part of or bordering upon the railway, are national advantages contributing to the welfare of the community at large.

If such a change could be effected at once very many improvements in the mode of dealing with the traffic would

appear feasible. Thus trains might be despatched at more frequent intervals—trains of lesser magnitude, capable of travelling at a higher rate of speed. It is obvious that this might also, to some extent, be accomplished by the steam locomotive, but to do so would mean a large increase in the number of engines and tenders, increased engine-shed accommodation, and all attendant expenses.

In my official capacity it is not my duty to determine the speed at which trains should travel, but I cannot refrain from expressing my conviction that if it were possible to lessen the enormous difference which now characterises the speed of passenger and goods trains great advantages would follow. This can only be accomplished by lessening the mass of the goods and mineral trains, and bringing them more under the control of the brake—a result which probably will never be attained under the steam locomotive régime.

The advantages that would accrue from a facilitation of the traffic scarcely calls for demonstration. Wherever the traffic is of a mixed character, involving the movement of trains at speeds varying from, say, twenty to sixty miles an hour, time must, even where scheduled time is observed, be sacrificed; and this loss must be greatly aggravated by the shunting of the heavy trains for the passing of those of a preferential character. The magnitude of the results arising out of this is not, perhaps, fully appreciated, for the existing mode of working the traffic scarcely admits of its consideration. But let us assume that in shortening these slow and heavy trains we are able to run them at a speed of not less than forty miles an hour. As there would be no shunting for the reason that, with the exception of the express trains, all would be moving at about the same speed, it is clear we should practically double the capacity of the line, and that without increasing the labour charges, because, although we double the trains, we halve the time. The number of trains that would come under this category would probably be 75 per cent. of the entire number, and if the method would admit of the acceleration of the expresses also it may well claim an increased capacity of 100 per cent. In other words, such a result would avoid that duplication of lines which is now unavoidable and which is adding so many millions, year by year, to the capital account.

The operation by electrical means of the passenger traffic as it is conducted to-day would appear to present no difficulty, for if necessary each carriage could be provided with the necessary motors for its propulsion ; but to work a railway economically—to reap the full advantages of an electrical service—it is necessary that the entire traffic of the line, goods as well as passenger, should be worked by the same means. To work one class of traffic by electricity and the other as at present, by steam units, although such a course is quite practicable, would involve a large increase in both capital and current charges; for the cost of establishing and operating electrical working for the passenger traffic would be very little less than it would be if dealing with the entire traffic, and there would still remain the cost attending that portion worked by the steam locomotive. Such a course appears to me impracticable. Therefore in considering the initiatory stage of replacing the steam by the electric locomotive, we have to face the present condition of traffic—to deal with the trains as they are made up for the former type of motor. Assuming it were determined to test the possibilities of electricity on a given section of a line of railway, whatever that section might be—whether terminal or intermediate—the electric motor would require to haul the trains that might reach that section of line as they were handed over from, or required to be carried forward by, the steam locomotive. It would, in fact, have to take the place of the latter and do its work. It may be said its capabilities to do this under all conditions has not been proved. It will, however, be clear that, assuming one electric locomotive incapable, there is no reason why two should not be coupled together in the same manner that steam locomotives are coupled. And in doing so it is worth while noting that we should reap some advantage, for not only would it be possible for the two to be controlled by one man, or one set of men, but in distributing the weight over a greater wheel base we should, to that extent, reduce the impact on bridges and other structures over which the vehicles pass. The importance of this will be apparent when we realise that the total weight of a modern locomotive and tender loaded exceeds 100 tons; that of this weight some 34 tons is comprised within a wheel base of 9 ft. 6 in.; 26 tons and 24 tons

each within 5 ft. 6 in. The tendency of the day is to increase the speed of passenger trains and the load of the goods and mineral trains, and to this end to employ larger and more powerful engines. In either case this course must involve greater stress on both permanent way and structural works; and to this extent it would appear that the two electric locomotives would be more acceptable to the engineer of the line than would the steam locomotive.

Much interest no doubt attaches to those railway conversion problems in hand here and in other countries; but assuming them proved—assuming them to be a success, would that success be deemed sufficiently definite to lead to its adoption on main lines generally? I scarcely like to commit myself to that opinion. I have full faith that our railways will be worked by electrical agency, but I want, with you, to look the probability squarely in the face. Every line of railway has its own mode of dealing with its traffic, and the character of the traffic is not the same on all lines. The only satisfactory way to prove the power of electricity to meet existing conditions is to impose upon it the work to be done. To do so on a suitably selected section of line would not be a great tax upon the resources of any one of our great railway companies, especially as it need not in any way, for the time being, derange the steam-worked traffic passing over that section of line.

Now let us look at the subject from another point of view. Electricity is credited with the power of accomplishing greater speed at a less cost than steam. An impression is abroad that greater facilities for rapid transit between large centres of commerce are a necessity of the day. If it should transpire that electrical propulsion is inapplicable to main-line traffic as a whole—a conclusion which few would, even at the present moment, accept—it will unquestionably lead to the establishment, between the chief commercial centres, of high-speed passenger electric traction on independent lines. Communication between Manchester and Liverpool has, so far, been met—and one would say, amply so—by three lines of railway, all running a good train service, yet the construction of an electric line on the Monorail system has received Parliamentary sanction. It is an object lesson, and tempts me to ask whether the requisite powers would not have been preferably granted to one of the

existing lines of railway—a line of railway capable of interchange of stock and of connection with other lines—to employ electrical agency as its motive power had powers for that purpose been sought.

Nothing could be more disastrous than that competition of such a character as, for instance, that thus initiated between Liverpool and Manchester should arise. Whatever success may attend competitive electrical enterprise in this respect must be, to some extent, prejudicial to the established systems. If the former should prove a pecuniary success, the reverse must be the condition of the latter. The capital invested in existing railways exceeds thirteen hundred million pounds. The wholesale depreciation of such a vast sum, the interest of which forms the income of numerous families and annuitants, would be little short of a national calamity. Naturally, were independent electric lines of railway to be established between the chief centres of commerce it would still leave a large mileage of the existing lines of railway unaffected by them, but is it from those parts of a railway system that the earnings come? The consequence must be, at the least, a decreased dividend, and probably in the end an enforced establishment on the older lines of a similar electric service between large towns.

The work of the railway engineer is to construct railways; and if the opportunity arises he will not be deterred from doing so by any consideration of the injury his work may inflict upon existing interests. The way to prevent him from doing so is to make it clear that there is no profitable need for any such addition; and this can only be accomplished by the existing systems showing that they are prepared to avail themselves of the same means—to afford as far as possible the same facilities and advantages as are to be derived from independent electrically worked lines.

It has been advanced that the existing lines of railways are unsuitable for higher speed; that the stock is cumbrous and that the system is generally unsuitable. This has to be proved.

Railways have to face the fact that electricity as a motive power is before them. That if it is not applied to the existing systems—if they do not elect to avail themselves of

it, it will come independently, and in competition with existing interests.

To attempt to approach the subject in a piecemeal fashion by dealing with a branch line here or there may be of service, but it can scarcely affect the main issue. While a small branch line is being converted, new lines between important centres will be constructed, and the passenger traffic between those centres will at least be split between the old and the new service. No one doubts the ability to apply electrical energy to branch lines, but many will doubt whether the traffic of a branch line can be so regulated as to form a continuous and remunerative service throughout the day. With main lines there can be no doubt of a regular demand, while most branch lines can with convenience be dealt with from the main-line power-station. Manifestly, however, if the trunk lines are eventually to be operated electrically, whatever may be done in relation to branch lines should be done with a view to harmonise with that system which will be ultimately employed on the main line. I do not presume to indicate what that system may be—whether alternating, or direct current, but it is clear that for main lines an overhead electrical service is inadmissible; and equally, to my mind, is a rigid or semi-rigid rate of speed. With a line carrying one class of traffic, this latter question may not be so important, but on lines carrying a mixed traffic this cannot be so, for the power to vary the speed is a factor which must have an important bearing upon the working of the line. The speed, subject to a maximum limit, must be in the hands of the driver.

To those with whom may rest the privilege to establish electrically worked lines I would with all respect venture to say: Be careful that you do not retard that great work which sooner or later must invite attention. In the establishment of light high-speed, point to point, passenger lines little difficulty may be encountered. It is not, however, with them that the interest of the country needs your aid, so much as in the conversion of those lines which are already established. It is where competition of a fruitless character —fruitless in that it will not prove productive of a return to the shareholder of the new more than to the shareholder of the old—steps in that capital will be squandered.

The observations with which I have thus far troubled you are the result of careful consideration inspired by a belief in the advantages of that new power which is before us. In the meanwhile the demands of a railway service have to be met by the means at our disposal. In it electricity is playing its part. In no way derogating from that useful service it has always rendered railway enterprise, its field is ever extending. In lighting, in local application of power for pumping, for lifting, traversing, and other purposes its utility and adaptability, wherever it has been applied, is such as to create a desire for its extension. So far it cannot, however, be said that its full advantages are being realised. To reap these advantages it is necessary that the schemes under which it is employed should be more comprehensive, capable of dealing with a more extensive service. Probably the nearest approach to this condition yet attempted is the high-tension generating station laid down by the Midland Company at Highgate Road, Kentish Town, which at present serves to light the Kentish Town, Camden Road, and St. Pancras passenger stations, together with the goods stations at Somerstown and St. Pancras, the day and night coal depôt at Somerstown, the Midland Grand Hotel, various cranes, traversers, and pumps. The output of this generating station was for the past year 2,081,129 k.w. hours with a load factor of 40 per cent.

There are few railway companies who do not recognise the advantage of electricity for lighting their offices, goods yards, and depôts. In no instance is space or time more valuable than with a railway service. The ability to load and despatch five trains where, under the old and inefficient mode of lighting, only four could be disposed of in the same time is equal to a saving of 20 per cent. in capital outlay for buildings and land quite independent of questions of labour and rolling stock. I often doubt, although the advantage of electric lighting is so freely admitted, whether this great and important fact is realised. The North-Western, the Lancashire and Yorkshire, the Brighton and South Coast, the Great Eastern, the Great Western, the Great Northern, and other companies are reaping the advantages of their various installations. Still there are fields of usefulness, embracing large economies of which advantage is not being

taken. These are to be found chiefly in relation to goods warehouses and in the large workshops of the companies. The value of electricity for workshop power has been so fully demonstrated in papers read before this and other institutions; it has been in so many cases applied with so much success, and attended with so much economy, that it is difficult to understand why it has not equally readily found a footing in railway workshops and warehouses. An object-lesson is that of the Burlington Railway Shops at Hanibal, Minnesota. The entire shops are operated electrically, boiler-house, lifts, turntables, cranes, etc., the total connected load exceeding 900 H.P.

The London and North-Western, the North-Eastern, and the Lancashire and Yorkshire Railway Companies have made the most use of electrical energy. In many instances each of these companies have, with evident advantage, replaced old and practically obsolete modes of operating cranes and tools by electric motors. The latter company operates its goods depôt at Oldham Road, Manchester, entirely by electrical energy—lighting, cranes, hoists, and capstans; the provender mill and warehouse adjoining being similarly operated. The new station at Bolton is to be similarly equipped for both passenger and goods work, and the signals and points of this station are to be worked electro-pneumatically. Many other portions of their system also employ electrical energy for various purposes. In their workshops considerable advantage has been taken of this source of power, always to good purpose. At Fleetwood a large elevator is similarly worked. The London and North-Western are preparing to work the whole of Crewe station electrically. The Lancashire and Yorkshire have also at their Lockwood and Castleton stations electric locomotives, the property of private firms, moving the traffic of those firms. These are worked from an overhead conductor.

That I may not labour you with many details I have, by the courtesy of the various responsible officers of the companies named, prepared and attached hereto a schedule of the chief work in this respect in operation on the principal British railways; and, similarly, I am also, by the courtesy of the electrical engineers of these companies, enabled to append details of block signalling and telegraph plant.

Here it is only necessary to quote the chief features of these schedules, viz.: Arc lamps in operation, 7,182; Incandescent lamps, 85,683. Electric energy applied to power purposes, 10,527 H.P. In telegraphs the total mileage of wire employed on these lines for railway purposes approximates to 113,000; wires maintained for the Post Office, 86,000. Number of instruments, 158,597.

In telegraphy there is little to note otherwise than to record a continuous growth of system. As traffic and competition increases so increase the demands on the telegraph service. No form of instrument has, however, proved of greater service in working the trains than the telephone. It has, in fact, become indispensable on all the main lines.

In the interlocking of the electric block signalling instruments with the mechanical signals comparatively little progress has been made. The London and South-Western, and the South-Eastern—Chatham and Dover section—show the greatest advance in this respect.

Electricity as applied to the lighting of railway carriages is steadily making its way. Some 3,000 vehicles chiefly fitted with what is known as Stone's System are now running.

Why electrical energy has not made more headway on railways it is hard to determine. We see that with two or three companies it is being employed to some extent, but in no case to that extent which, from its known utility and advantage, one might anticipate would be the case. Possibly the ready provision of power which will be placed at the disposal of most railway companies by the establishment of those electrical power schemes which are now taking shape may prove a means to this end. The cost of laying down generating plant is undoubtedly one reason why the progress has not been greater.

Distribution of Power.

But a few years since it was not unusual to hear electricity spoken of as in its infancy. More recently any such reference has been keenly resented and, in a measure, properly so, for with the invention of the dynamo, electricity undoubtedly passed beyond the infant stage. The genera-

tion of electricity is now limited only by the motive power necessary to produce the motion by which it is evolved; it can be obtained in any quantity. But, let me ask, is not electricity in its application and use still in its infancy? View it in its operations of to-day, and conceive within your mind the extent to which it is capable of being employed.

Electricity is but treading on the fringe of that vast domain it is destined to serve. Employed at first to meet isolated demands, it has passed on to fulfil higher and more important duties; and it is only now, in the establishment of those Power schemes, destined to serve large areas, foreshadowed in the able address of your Past-President, Dr. Thompson, that we are approaching those economical conditions which will confer upon the commonwealth its fullest advantages.

In the development of these schemes for the distribution of electrical energy, not merely for power, but for all purposes useful to the community at large, we as a nation are by no means singular. Other countries are equally availing themselves of them for various industrial purposes. Great Britain cannot boast of some of those great natural advantages enjoyed by other countries, but, although water power is not ours to command, we have in our coal fields a product which there is every reason to believe will prove of equal value.

The time has come when we have to put to ourselves the question: To what extent are these schemes destined to aid economical manufacture, and the conveniences and needs of every-day life? To some extent this is an unsolved problem, but that they will prove a great and powerful factor in all industrial operations there can be no doubt.

Competition in the production of all marketable articles will in the near future be extremely keen. Equally sure it is that the advantage will lie with those who are able to produce at the least cost. It is only when we fully realise this that we see how important it is, in the welfare of the country, that every means by which production may be cheapened should receive our most careful and considerate attention. We feel that we are entering upon a contest with others, others possessing to all intents and purposes equal if not more favourable means than ourselves for the produc-

tion of those very articles which we propose to produce. We see that in the establishment of the means for furnishing to those who need it the power which is to aid in this economical commercial propaganda, other lands are in advance of us; that we are only now awakening to the means by which it is given us to compete in this race.

The advantage of such a service does not rest merely in the fact that we may take and pay for just such power as we need, but in the fact that space—a valuable asset in most industries—is economised. When we compare the space occupied by one or more electric motors with that absorbed by a steam plant we cannot fail to realise that this mode of acquiring power is attended by more than one advantage.

The extent to which it may be carried must naturally resolve itself into a question of how far it will pay to do so. If it is confined to those localities where population is already congested, it will but tend to aggravate that condition of life, the relief of which it is felt is becoming one of the most serious questions of the day. A cheaper mode of construction would admit of greater latitude, and to this end it might be of advantage to consider whether, in practically unfrequented parts, the regulations which now attend the use of overhead wires, would admit of such modification as would confer upon these schemes a status which would tend to place them more upon a level with those of other countries.

Gentlemen, you will, I feel, pardon me for thus entering upon a subject so intimately connected with commercial life, but the subject is one of so much material interest at this moment that it is impossible to ignore it, and if the establishment of these power schemes is to be of that service to our industries which may be fairly anticipated, it is of the greatest importance they should receive at our and other hands all the aid in our power. It is in searching out means for effecting economies and securing the higher attainments of life that science plays its most useful part, and we must not forget its ultimate object. Science is but a means to an end. When Faraday was engaged in investigating the relationship between the electric current and magnetism, he saw that there was in his discovery that which was new, but he could form no fixed idea of its future utility. Others working upon the foundation he established, have given to

the world the means by which his discovery is capable of being serviceably applied to the ameliorations of the duties of life. It is so with most great discoveries. The scientist lays bare the principle. Others take up his parable and apply it to the use of mankind. It is in its application that we recognise the merit of the discovery and pay homage to its author. Its end has been for the benefit of the beings of the world. Faraday had no conception of the value of that which was to spring from his discovery, nor even now do we know the depth of its value, yet there is no name more venerated by every disciple of the electrical profession, or one to whom a greater debt is due by the world at large.

Conclusion.

I feel that I cannot close these remarks without tendering to the members my hearty congratulations on the progress of the Institution. Although the funds at our disposal are not, in the interest of the objects of the Institution, so great as we could well desire, and although we have made but little tangible progress in the establishment of a permanent home, and still, with gratitude, record our indebtedness to the Institution of Civil Engineers for that great and generous consideration so gracefully accorded us in the use of this noble theatre, the Institution is doing work of which we have reason to be proud. The membership is a growing quantity, and with its growth the field of operations is widening. Local Sections are adding their quota to the work done, in the promotion and discussion of subjects material to the knowledge and development of electrical science; still the advantages of electrical agency and the simplicity of its application are largely unknown. Compare the simplicity of an electric motor with the details of a local steam or gas plant, and conceive, when electricity is brought to our doors and its advantages are more clearly understood, how much of that machinery from which motion is now produced will be displaced by the electric motor. It is for you, gentlemen, in your communications and papers to be read and discussed before this and kindred institutions to remove this deficiency, to show by what is being daily accomplished the economies which lie in the use of electricity and the advantages it possesses over other forms of distributed energy.

Nor can I abstain from tendering to you my congratulations on the work of utility which awaits your efforts. No profession has before it so large a field as that which constitutes the basis of this Institution. I would that I could congratulate you on the extent of work done. Electrical development in England has not been so satisfactory as it should have been. In 1877 I read before this Institution, then the Society of Telegraph Engineers, a short paper descriptive of the first application of the electric light in England. The system there referred to was in 1879 employed to light the Victoria Embankment. It was not a success and was abandoned. For nineteen years this, the finest roadway in England, remained indifferently lighted by gas. The inauguration of the London United Tramways took place no less than ten years after the establishment of the first electric railway in London! Over-legislation—that great desire to protect the subject, often at the cost of that to which he has to look for his means of support, has, no doubt, retarded electrical progress, and consequently the production of electrical machinery. Oft do we hear the cry for education. Educate! Educate! Certainly, let us educate, but of what avail is education without experience? Are our engineers deficient in education? Do those electrical plants and installations which have been established indicate a want of knowledge? Do they fail to favourably compare with those of a similar character in other countries? Why is it that America has forged ahead in electrical applications in the manner she has? Is it due more to education than experience? It is experience that has gained for her engineers and manufacturers the position they have attained in the provision of electrical equipment. It is this experience that has enabled them to determine that which is adapted to meet the demands arising out of this new power; to standardise it, and lay down plant for its manufacture.

Experience can only be obtained by actual work, and that actual work has been, by those to whom power to put it into operation has been assigned, delayed till the last moment when, perforce, much of it has had to be entrusted to those who were prepared to provide promptly the necessary parts. Work has been delayed, experience sacrificed, and much that should have enriched British industry

has passed into other channels. I am sure that I do not stand alone in echoing the expression of the President of the Glasgow International Engineering Congress, Mr. Mansergh, the late President of the Institution of Civil Engineers, that what is needed is greater liberty—greater freedom—less restraint! Is electrical science in those applications to which I have referred destined to be of service to the public weal? Is it now serving the community with advantage? If so, is it desirable that Statute limitations should interfere to preclude or to prejudice its progress? If found to be undesirable, or in any way injurious, nothing could be easier than to restrain its use. To do so in anticipation is to stay its progress and deprive the country of its value. Do not let us lose sight of the fact that when railways were being established throughout the country there were towns—certain towns—that declined to be associated with them, but in a very short time they became sensible of their folly and had to seek the suffrage of the railway—only, in some instances when too late, for they have been left out of the main route, and have never recovered their prestige. In these distribution of power schemes the country has before it something of value to its commerce equally great. Assume that a district desires to be exempt in order that it may provide for itself. Unless it can produce as economically as the larger scheme it must increase the local cost of production and injure its users, or drive them into another area whence they may be more advantageously served.

It is in the full belief that electricity is destined to prove of the greatest service to the commonwealth and that its advantages have been too long retarded, that I have ventured to submit to your consideration these remarks. In doing so my effort has been to view the subject from that broad standpoint—the national interest; the benefit of the greatest number. This Institution is a composite body, embracing within its folds every branch of electrical science, having various interests to protect; but of this I feel sure that however varied those interests may be one and all its members are animated by but one desire—the progress and the welfare of the country. We believe that electricity is to play a very important part in engineering work, and we are ambitious that England shall not sacrifice that high position

in engineering science which has for so long distinguished her.

In what way, by what means, whether by private enterprise, or by municipal effort, electrical progress is effected is not so material as that it is effected. So long as its fullest advantages are placed at the disposal of those who desire to avail themselves of them, you, gentlemen, as well as I, will welcome the means, whatever that may be.

SCHEDULE A.

Details of Electric Lighting and Power Installations on the following Railways:—

Railway.	No. of arc lamps in use.	No. of incandescent lamps (16 c.p.) in use.	Approximate H.P applied to Power purposes.	Particulars as to purposes to which Electrical Energy is applied, and of important works in contemplation.	No. of Coaches lighted by Electricity, and system employed.
Caledonian	480	6,014	90	Using for drainage pumping and hydraulic pressure pumping for operating signals. Also in horse-provender stores (where provender is mixed for 1,070 horses). *New Works in Progress:* *Glasgow Central Station.*—Power station of 1,050 kw. capacity for lighting and power—for hoists, pumps, fans, traversers, etc. *Edinburgh.*—500 kw. additional plant, for hotel lighting and other purposes, with two thousand 16 C.P. lamps. *Stirling Station.*—Five hundred incandescent lamps (station and offices). *Perth Station Hotel.*—Four hundred and fifty incandescent lamps. *In contemplation:* *Glasgow, Buchanan Street Passenger and Goods Station, Head Offices, etc.*—Power station of 2,000 kw. capacity.	27 (Stone's) 3 (Vickers and Maxim)
Cheshire Lines	219	763	Nil.	Used only for lighting.	8 (Stone's)
Glasgow and South-Western	185	5,050	40	Applied to overhead cranes and shop traverser.	6 (Stone's)
Great Central	716	6,168	333	For air pumps, water pumps, electric lifts, travelling cranes, wood working machinery and iron turning. Lighting comprises whole lighting of following:— *Goods Depôts.*—Marylebone, Leicester, and Nottingham. *Sorting Sidings.*—Neasden, Woodford, and Annesley. *Warehouses.*—Marylebone, Leicester, Nottingham, and Liverpool. *Passenger Stations.*—Marylebone, Woodford, Leicester, Nottingham (Victoria), Sheffield (Victoria), Oldham (Clegg Street), and Manchester (London Road). *Receiving Offices and Depôts.*—London, Bradford, Liverpool, and Manchester.	11 (Stone's) 1 (Vickers and Maxim)

Great Eastern	8	405	Nil.	No motor load.	9 (Stone's) 1 (by cells)
Great Northern	927	9,842	1,198	*Doncaster Works (Locomotive and Carriage and Waggon).*—Used for working one hundred and sixty travelling cranes (35 tons and 20 tons load each), two walking cranes, one engine traverser, and for driving shafting in sections and some machine tools with separate motors.	88 (Radcliffe's)
Great Northern (Ireland)	84	529	750	Employed for working a tramway round the Hill of Howth—five miles. Generating house is at Sutton, and there are three engines, each of 250 H.P.	231 (Stone's)
Great Southern and Western (Ireland)	57	15	Nil.		
Great Western	166	8,764	Nil.		21 (Stone's)
Lancashire and Yorkshire	500	6,800	1,460	*Oldham Road Goods Station (Manchester)*, wholly worked by electricity, viz., twenty-two 18 H.P. capstans, two 40 H.P. motors operating waggon hoists; motors driving traversing cranes, gantries, and a number of 15 cwt. jiggers. Provender mills adjoining also operated electrically. The whole of these premises and yards also electrically lighted. *Bradford Warehouse*—Three high-speed travelling cranes for unloading and storing wool, each operated by three motors. *Bolton.*—A power station has been built for operating whole of station—capstans and cranes (including 40-ton Goliath crane with longitudinal travel of 200 yards) in goods yard; hoists in warehouses and on station platforms; air valves in connection with pneumatic signalling, and complete lighting of passenger station, offices, goods yard and signals. *At various stations.*—A number of small motors—of 3 to 5 H.P.—operating luggage hoists between subways and platforms, including an overhead Telpher track for parcels at Manchester, Victoria Station. *Liverpool Hotel.*—Passenger, dinner, and coal lifts. *Newton Heath Locomotive and Carriage and Waggon Works.*—Portion of lathes, shafting, cranes, and fans. *Steamers, Tug-boats, and Dredgers.*—Lighted (including mast, side, and signalling lights), and fans operated electrically.	6 coaches and 3 saloons (Stone's)

DETAILS OF ELECTRIC LIGHTING AND POWER INSTALLATIONS ON THE FOLLOWING RAILWAYS (*continued*) :—

Railway.	No. of arc lamps in use.	No. of incandescent lamps (16 c.p.) in use.	Approximate H.P. applied to Power purposes.	Particulars as to purposes to which Electrical Energy is applied, and of important works in contemplation.	No of Coaches lighted by Electricity, and system employed.
Lancashire and Yorkshire (*continued*)	...	...	...	(The lighting of the *Fleetwood Docks*, including a large grain elevator, is accomplished by means of electricity.)	
London, Brighton and South Coast ...	301	800	Nil.	But question of employment for power purposes is *under consideration.*	271 (Stroudley and Houghton's) 215 (Stone's)
London and North-Western	425	12,800	3,300	The working of points and signals, warehouse cranes, capstans, hoists, pumps, and shop tools.	830 (Stone's)
London and South-Western	76	220	Nil.	*Southampton Dock.*—Large electrical installation.[1] *Steamships.*—All "fitted" with electric light. *Fitting up Salisbury Station* (about eight hundred incandescent and thirty 500 watt arc lamps).	326 (Stone's)
Midland	1,885	13,731	750 installed. 250 estimated for new work.	50 H.P. working pumps at 700 lb. pressure for hydraulic lifts. 25 " " compressor for pneumatic drilling, &c. 78 " " pumps. 83 " " overhead traversers. 20 " " waggon traversers. 135 " " capstans, 35 " " cranes, lathes, &c. 15 " " fans. 250 " " granary machinery—chaff-cutters, elevators, crushers, hoists, &c. 9 " " miscellaneous.	11 (Stone's)
Midland Great Western (Ireland) ...				Nil.	100 vehicles (Stone's)

orth British	369	2,681	10	One 10 H.P. motor for passenger elevator.	7 (Stone's) 291 (Carswell's) 2 (system not stated)
orth-Eastern	429	7,306	2,204	Travelling jib cranes, overhead travelling cranes, capstans, luggage hoists, goods warehouse travellers, ticket-printing and ticket-destroying machines, punching and shearing machines, saws, grindstones, paint mills, lathes, coke crushers, and ventilating fans. *In contemplation:* Important installations at Leeds, Hull, and West Hartlepool. Electric overhead travellers, cranes, hoists, and capstans for goods warehouse, Newcastle, and a number of arc and incandescent lamps being installed at the latter place, and not included in summary.	
orth Staffordshire	47	1,403	20	Used for driving machinery: lathes, cranes, luggage lifts, air pump, ventilating fans, and for cooking, etc.	79 (modified Stone's)
uth-Eastern and Chatham	308	2,392	122	*Slade's Green Locomotive Shed.*—Motors employed for pumping, for coaling engines, and for lathes, etc., in workshops. *In contemplation:* Installation for *Queenborough Pier* for lighting and for cranes and capstans.	925 (Stone's)
Totals....	7,182	85,683	10,527		3,452

1 Details not furnished.

SCHEDULE B.

Mileage and other Details of Telegraphs and Block Signalling on Undermentioned Railways.

Railway.	Mileage of Line on which the Electric Block is interlocked with Mechanical Signals.	Number of Block Posts where Mechanical Signals are operated by Electricity.	Number of Telephones for all purposes.	Number of Telegraph Instruments of all kinds, including Block.	Mileage of Wire employed for Railway purposes.	Mileage of Wire maintained for the Post Office Telegraph Department.
Caledonian	25	Nil	1,629	16,688	6,890	5,120
Cheshire Lines	1¼	Nil	260	1,586	1,184	725
Glasgow and South-Western	4	13*	359	1,620	1,814½	1,888
Great Central	16¼	Nil	918	7,036	4,259	1,209
Great Eastern	59	109	715	11,704	6,777	4,802
Great Northern	3¾	16	684	10,427	7,747	4,379
Great Western	16	Nil	2,155	25,924	15,256	14,003
Lancashire and Yorkshire	Nil	Nil	1,950	8,380	5,229	2,268
London, Brighton and South Coast ...	80	Nil	600	2,944	3,500	2,434
London and North-Western	Nil	Several Signals and Points are worked experimentally at Crewe (by Signal Department)	2,361	10,450	13,500	8,200
London and South-Western	345	(Experiment) 6 Automatic Posts	1,213	14,663	7,325	7,947
Midland	25	Nil	2,820	20,344	12,845	15,243
North British	5½	Nil	562	3,466	7,193½	3,622
North-Eastern	1	Nil	1,820	14,726	10,767¾	3,449
North Staffordshire	Nil	Nil	418	1,181	850½	433½
South-Eastern and Chatham	350 (Double line)	Nil 55 Electrical Shunting Signals in use	853	6,504	4,613	4,804½
Great Northern of Ireland	Nil	Nil	161	242	1,338	3,280
Great Southern and Western of Ireland	—	—	109	311	†	†
Midland Great Western of Ireland ...			32	401	1,167	2,210
Totals	913¾	138	19,619	158,597	112,256	86,017

* *G. & S.W. Railway.* 66 Electric Signals operated by means of motor connected with each arm, worked from 30-volt accumulators. 57 disc shunt signals operated electrically by means of electro-magnet, worked from 8–12 volt accumulators. These numbers will be considerably increased when installation completed.

† The total mileage of wire is returned at 1,061, without distinction as to the purpose to which it is applied.

Sir WILLIAM H. PREECE, K.C.B., F.R.S. (Past-President): It is my very pleasant duty to have to propose a vote of thanks to Mr. Langdon for the address that he has just delivered to you. Mr. Langdon and I are very old friends; we have been colleagues together for forty-seven years. For nearly twenty years of the early part of our lives we worked industriously together to improve as far as we could the railway service of this country. Few of you perhaps are aware of the fact that nearly the whole of my earlier life was spent on the railways. I have always looked on my railway career as the best time of my life. Mr. Langdon has fortunately stuck to the railways, and he has given you to-night the result of the careful observation, the persistent thought, and the clear brain for which he has always been distinguished. I have one little bone to pick with Mr. Langdon. He is always cheerful in the transaction of his work; he has been a little doleful to-night about the position of the electrical industry in this country. I am afraid he has perhaps acquired a kind of a fashionable flavour of despondency that passes through our Press. Most people who take their views of this country from the Press will say, "Poor old England, it is going to the dogs. Look at America, look at Germany; see how they are surging ahead." Why, can America, or Germany, or France produce a diagram like Mr. Langdon has exhibited showing the wonderful increase in the membership of our Institution? Can all the world put together show a curve that speaks in stronger language of the growth of electrical enterprise in this country? We in this room, when we started this Institution of Electrical Engineers, were thankful to get two rows of members present, and I have often lectured to one row in this very hall. Look at you now! If there is any new subject of any kind to be brought forward, do you not crowd into this room, and are we not all delighted to talk to you? Is that an indication of the decay of electrical enterprise here? On the contrary. Take up that estimable paper *Lightning*—it is now, I believe, called by another name—open the centre sheets. Week by week, do you not see new towns lighted up by electricity, new motive power here, and progress everywhere? Why, gentlemen, I am ashamed of you as Englishmen when you deliberately come before us and decry your own nation. There must be patriotism, and we must look upon our progress as encouraging. We must do all we can to put our shoulders to the wheel, and not go about rubbing our eyes and crying over what is really, perhaps, spilt milk. Mr. Langdon has been talking about railways. Why, we have made more progress in working railways by electricity in this country than America or anybody else. The Mersey railway at Liverpool started in 1892, and has been nearly ten years at work. The South London Railway and City and Waterloo Railway are all independent railways, and we claim the Central London Railway, although it was fitted up with American apparatus. Still it was started with English money, and is managed by English people, and it is on English ground. There was a great author who always ended his speech by saying, "I will never despair of my country"—and that is my case. Whenever I have an opportunity in this hall or anywhere else, I will persist in maintaining that the progress of this country is not to be wept over, but it is

Sir William H. Preece.

Sir William H. Preece.

to be received with a great deal more cheerfulness and with a certainty that we are doing all we can. If there is want of progress, who are the culprits? Not the Institution of Electrical Engineers, not our gallant professors, but it is those gentlemen who hold the purse in the City of London who will not bring out the money to carry out these enterprises. I am delighted with the address Mr. Langdon has given to us to-night. I have the pleasure of proposing, "That a hearty vote of thanks be offered to Mr. Langdon for his most interesting address, and that with his permission the address be printed in the Journal of the Proceedings of the Institution."

Mr. Gray.

Mr. R. K. GRAY: Gentlemen, I have very much pleasure in seconding the resolution proposed by Sir William Preece, and I think that in your name I may say to Mr. Langdon that we are very much indebted to him for his address. The address he has just given to us is exceedingly suggestive, and I believe that all those who have heard it will come to the conclusion which Mr. Langdon doubtless wishes us to arrive at—that there is a very large field for electrical engineers to work in. The views given in the address are remarkable in the fact that they come from the most distinguished electrical engineer in the railway service of Great Britain. I beg to second the resolution.

Prof. Perry.

Professor JOHN PERRY: I have to perform the last function that a presidential ghost can perform in putting this resolution to the meeting. I should like to say with regard to the curve here exhibited, and what Sir William Preece said about it, there is no doubt that those small meetings which he addressed long ago were meetings of good, earnest men, but it does not follow that because they were few in number that therefore they were more devoted individually to electrical engineering and electricity than every member of our 4,000. I think that we are now much more careful in the selection of our members than we were even in our earliest days. The Pilgrim Fathers who reached Massachusetts in the *Mayflower* were few in number, and everybody descended from them brags about their awful morality and religiosity; but the eighty millions of Americans at the present time are trying to be individually just as good as every one of those Pilgrim Fathers. I have heard a a number of Presidents' addresses in this place, and I think that even Sir William Preece's address and every address I have ever heard contained a good deal of criticism of England. We are always criticising ourselves unfavourably. I think it is a good thing; but whether it is good or bad, we cannot help doing it. This self-inspection and self-depreciation is a characteristic of the Anglo-Saxon people, and it is a most interesting thing that foreigners actually believe us to be as backward as we say we are. There is no doubt that this gives us a very great advantage, for the foreigner is deceived, and we are kept up to the mark. One does not want to create any nasty feeling between ourselves and other countries at the present time, but there can be no harm in referring to the condition of France and England 140 or 150 years ago. Do you know that in 1756 there actually was a belief that all Englishmen were cowards, that England's greatness was of the past, that there was no future for England at all except being wiped out? Good electrical engineers are all fond of reading, and so they must remember what occurred immedi-

ately after that date. The great Pitt came, and in 2½ years we had cleared the French out of India. The pin-prick policy that hemmed in British settlers by Fort Duquesne on the Ohio was destroyed when we had cleared the French out of America altogether, and America became what it must always remain, English. So, gentlemen, as a matter of fact this habit we have each of us of depreciating ourselves belongs to our race and is a very good thing. It does not prevent our appreciation of good work, and this address of our President's is a good one. It enables us to see more clearly all the conditions of a great problem which must be solved in a few years. Prof. Perry.

Gentlemen, it is my pleasant duty to put this resolution to the meeting:—"That a hearty vote of thanks be offered to Mr. Langdon for his most interesting address, and that with his permission the address be printed in the Journal of the Proceedings of the Institution."

The resolution was put, and carried with acclamation.

The PRESIDENT: I am extremely obliged to you for the very kind manner in which you have received the remarks of the three gentlemen who have spoken in support of this resolution. I feel myself greatly indebted to each for the generous manner in which he has spoken of myself. I quite agree with Sir William Preece that if the gentlemen in the room had the control of the electrical affairs of this country we should have no reason to complain. A great many of those who are here, are here no doubt in anticipation of the progress that might have been made, and probably will yet be made. It is a trait of our character that when we get into any difficulty we soon find a way out of it. If there is anything impeding the progress of electricity, I have not the slightest doubt that we shall see it removed. The question in my mind has been: Has that progress been so great as it might have been? I hope I have not spoken in too deprecatory a manner, but I certainly, personally, have entertained the idea that the progress might have been greater than it has been. Gentlemen I thank you very heartily for the manner in which you have received this resolution. It is needless for me to say that the address is entirely at the disposal of the Institution. The President.

The Three Hundred and Sixty-seventh Ordinary General Meeting was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 28th, 1901—Mr. W. LANGDON, President, in the Chair.

The minutes of the Ordinary General Meeting held on November 21st, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

James Enright. | George Cambridge Weston.

Messrs. A. Russell and W. W. Cook were appointed scrutineers of the ballot for the election of new members.

Donations to the Library were announced as having been received from Mons. Guarini, and to the Benevolent Fund from Mr. M. Heaphy, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have to bring under your notice a circular which has been addressed to the Institution by Earl Grey with reference to a memorial to commemorate the services of Lord Armstrong. A public meeting has been called to promote this memorial, and subscriptions to a considerable amount have already been received. The circular states that the memorial will be twofold :—

" First, the erection of a Statue of Lord Armstrong by one of the most eminent sculptors of the day, in some conspicuous position in his native city and, second, the completion and equipment of the Durham College of Science in Newcastle-upon-Tyne, at which in the future as in the past special attention will be given to the teaching of physical science, in the hope of enabling the British manufacturer to keep abreast of his Continental competitors in all those departments of manufacture which depend on the application of scientific discoveries to industrial production."

It is thought that possibly members of the Institution might feel disposed to contribute towards this memorial, and if so I would suggest that they should communicate with the Secretary to the Memorial Fund, Mr. Henry J. Richardson, of 67, Westgate Road, Newcastle-upon-Tyne. He will be very happy to receive the names of any gentlemen who may wish to subscribe towards the memorial, and furnish any information which they may desire. The contribution may be appropriated to either of the objects indicated. I have now the pleasure to call upon Dr. Drysdale to read his paper.

A PERMEAMETER FOR TESTING THE MAGNETIC QUALITIES OF MATERIALS IN BULK.

By CHARLES V. DRYSDALE, D.Sc., Associate.

Numerous as have been the instruments devised for the testing of the magnetic qualities of materials, they are all open to the objection, from the electrical engineer's point of view, that they require specially prepared specimens usually in the shape of rods of some inches in length, which have to be accurately turned and perhaps faced. Not only is the preparation of these specimens troublesome, but it is very rarely that tests made on them are of practical value, as they cannot be prepared from the bulk of a casting or forging. As is well known, different specimens of iron, however carefully prepared, may show considerable differences in their magnetic qualities, and what the manufacturer requires is an instrument which shall enable him to determine the magnetic quality of any casting or forging, before a large amount of time and expense have been spent in machining it. If such castings or forgings could be tested and accepted or rejected immediately on delivery, a much greater certainty in the design of machines might be attained.

At the discussion on the Permeability Bridge of Messrs. Lamb and Walker which was brought before the Institution last session, both Mr. Evershed, Mr. Esson, and Mr. Hammond called attention to this want, and the writer feels that he is indebted to these gentlemen for directing his attention to the subject. The apparatus which is before you this evening was designed while returning from that meeting, and I hope that engineers may find it a satisfactory

solution of the problem. The importance of the matter must be my excuse for bringing before you a paper on such a hackneyed subject as iron testing.

A permeameter for commercially testing iron or steel for engineering purposes should, as far as possible, fulfil the following requirements:—

(*a*) It should be capable of testing specimens, either in the form of large or small castings or forgings, or in the form of rods or plates.
(*b*) The test should be rapidly effected.
(*c*) The apparatus should be self-contained and portable.
(*d*) The instruments should be direct reading, and the test should not require experimental skill.
(*e*) It should be capable of testing either the permeability, the retentivity, or the complete hysteresis cycle.
(*f*) It should be simple and strongly made, and should be capable of being easily checked or recalibrated if deranged. It should *not* depend on previously standardised specimens.

In the above list I think that I have mentioned all the most important points, and it will be seen from what follows, how far the apparatus now before you satisfies these requirements.

A few preliminary remarks on the principles which led to the design of the instrument may not be out of place, as they may lead to other solutions of the problem.

The various methods of testing the permeability of iron may be divided into three principal classes.

I. *Magnetometer methods.* In these the specimen is usually in the form of a long thin rod, and its magnetisation is measured by the external force it produces at some point.
II. *Ring methods,* in which the specimen is made up into a complete or split ring, the magnetisation being measured by search coil or by the attraction between the two halves of the ring.
III. *Yoke methods.* The specimen is here in the form

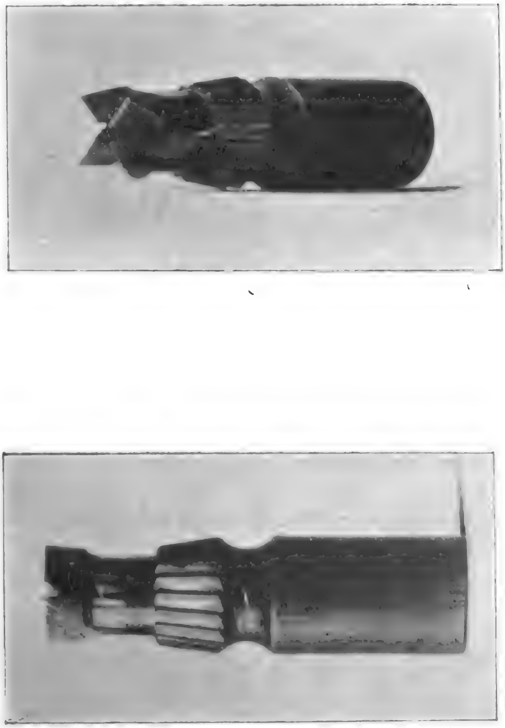

FIG. 1.—Drill.

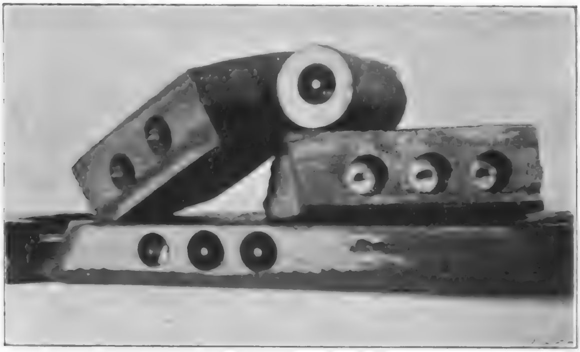

FIG. 2.—Specimens showing holes and pins

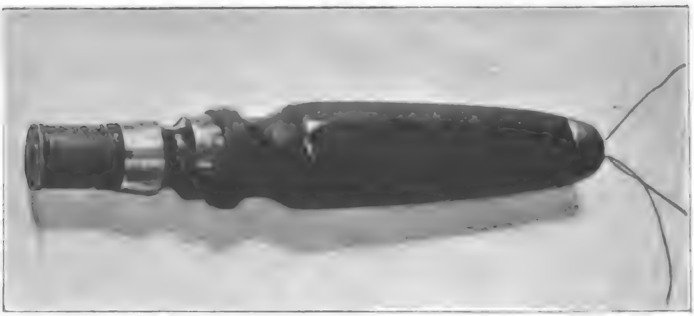

FIG. 3.—Plug.

of a uniform rod, and is provided with a heavy iron yoke or return path. Numerous devices are employed to determine the magnetisation.

At first sight one would look for some form of magnetometer test as being the most promising, but the difficulty is, first, that in irregularly shaped bodies the connection between the external force and the intensity of magnetisation cannot easily be arrived at; and secondly, that unless the specimen is very long in comparison with its transverse dimensions, its quality has very little effect on the field produced. It does not seem likely that any universal method can be devised which depends upon this principle.

The objection to either of the latter methods, from a practical point of view, is that if the ring or bar is of any great size, it cannot be prepared from the casting or forging. If, however, we can arrange to use very small rings or rods, there is no reason why they should not be drilled from the bulk of the metal to be tested. The rods could be drilled out by some form of hollow drill, while the rings could be easily cut out of the solid by a properly designed expanding drill.

The ring method, however, suffers from the further objection that the magnetising and search coils have to be wound through the centre of the ring, which would be exceedingly troublesome. Moreover, it would be somewhat difficult to ensure the exact dimensions of the ring. We are thus thrown back on the yoke method, and this may be carried out by drilling out a straight cylindrical specimen from the bulk, and inserting it in a yoke as in a Hopkinson Permeameter.

The writer has, in commercial testing, adopted the plan of making both the specimen and the greater part of the return path from the bulk of the material tested. A drill of a special form is employed, which is illustrated in Fig. 1. This drill cuts a circular hole in the specimen, conical at the top, leaving a pin in the centre of it, as shown in Fig. 2. In the instrument as usually made this hole is $\frac{3}{8}$ in. diameter and $\frac{5}{8}$ in. deep, and the diameter of the pin is $\frac{1}{10}$ in., but these dimensions could be considerably reduced if necessary.

The testing arrangement consists simply of a soft iron plug, carrying a bobbin on which are wound two circuits, a magnetising coil and a search coil, and it is represented

in Fig. 3. The plug is split and is turned slightly conical on its outside surface, while the drill cuts the cone of the same angle as that of the plug. It will thus be seen (Fig. 4) that on drilling the hole and inserting the plug, a perfect miniature permeameter is produced, which has an exceedingly good magnetic circuit, and in which either the permeability, retentivity, or hysteresis can be determined by ordinary methods.

Before going further into the details of the apparatus, it

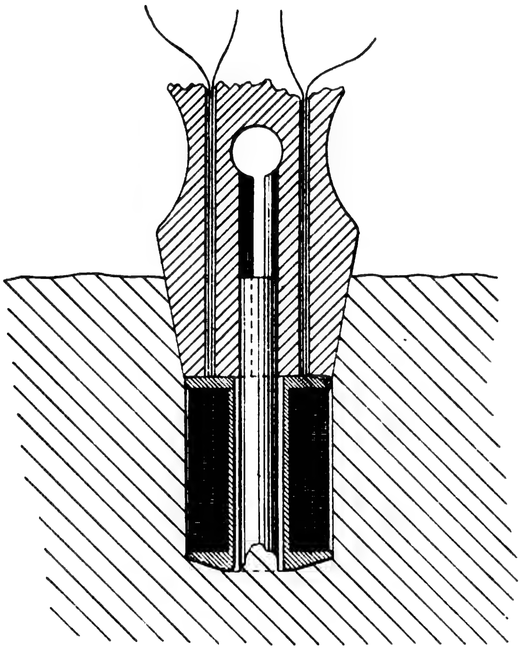

FIG. 4.—Section through Plug and Specimen.

will be well to say a few words about the drilling of the specimen. There are very few castings or forgings in which a hole of the size mentioned would not be admissible, probably in the places reserved for bolt holes, but in the event of its not being allowable, there is no objection to a boss being left on the casting in any convenient position for the purpose of test, and which could be cut off before drilling. This is analogous to the procedure adopted in optical work, where for large telescopes the discs of glass are cast with small projections from which prisms

can be cut for testing. For small castings, as above mentioned, it would be possible to reduce the drill and plug to half the dimensions above stated if necessary. The time of drilling appears to be about ten minutes in the case of cast iron, and about fifteen to twenty minutes in the case of wrought iron, but this appears to be a small consideration in comparison with the importance of the information obtained, and it may be possible to reduce this time considerably.

Fig. 5 shows the connections which are most simply employed. The magnetising coil M C of the plug is supplied with current from a battery B, through a regulating resistance R and ammeter G_1, and a reversing switch R S. Connection is also made from the search coil S C to a ballistic galvanometer G_2. On making, breaking, and reversing the switch deflections are obtained on the galvanometer G_2 which are proportional to the magnetisation of the specimen.

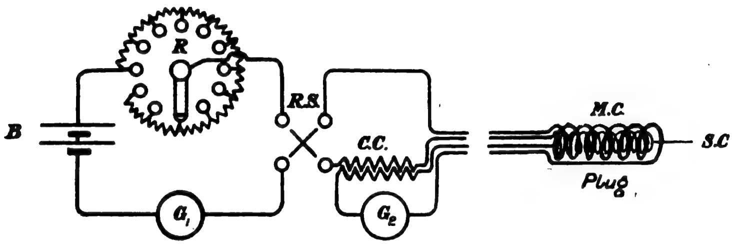

FIG. 5.—Connections for Ballistic Test.

In order to make the instruments direct reading it is easy to provide such a scale for the galvanometer G_1 that it reads the values of H. In the same way a scale is provided for G_2 reading the values of B directly. The permeability is then obtained, if necessary, by dividing the value of B by that of H; but it is generally sufficient to compare the values of B obtained with the curve of some satisfactory specimen.

In ordinary commercial testing of castings, etc., it would probably be sufficient to know the value of the permeability for one value of the magnetising force. In this case the arrangement may be further simplified by withdrawing the resistance R and galvanometer G, and simply arranging for the cells to give one definite current. The divisions on the galvanometer G_2 may then be marked directly with values of the permeability.

There are, of course, other methods of taking the observations, and two of them will be mentioned here, as different engineers may prefer different methods.

Zero-reading method.—The determination of the permeability of the iron of course simply resolves itself into the determination of the self-induction of the magnetising coil. Fig. 6 shows a very sensitive method of effecting this in which the magnetising coil M C is connected in one arm of a bridge, and an Ayrton-Perry variable standard of self-induction in the opposite arm. C_1 and C_2 are the two commutators of a secohmmeter, G_1 the galvanometer for measuring the values of H, while the galvanometer G_2 is simply a zero-reading instrument. The reading is then

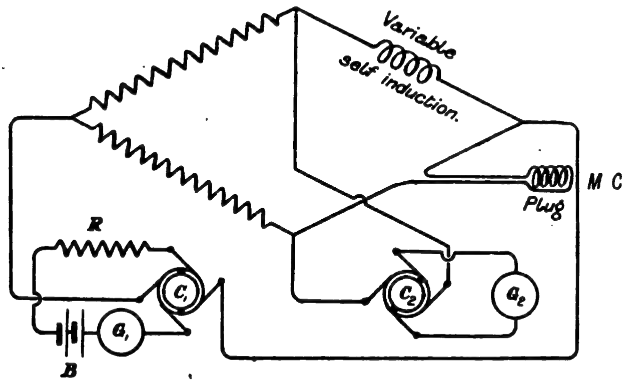

FIG. 6.—Connections for Zero Test.

taken by rotating the secohmmeter and turning the inner coil of the variable self-induction standard till balance is obtained. The reading on this instrument can be made to give the permeability direct, while that of G_1 gives the value of H. The galvanometer G_1 must of course be calibrated with due regard to the fact that the current divides in the two halves of the bridge, and that the current is periodically interrupted by the secohmmeter.

Where an alternating supply is available, the secohmmeter may be dispensed with and a telephone substituted for G_2. The alternating current might be supplied by a portable generator.

Direct Deflection method.—For those who prefer simply to turn a handle and grind out a direct reading, which

is apparently the highest ideal in an engineer's instrument, the connections may be made as in Fig. 7. In this case a secohmmeter is again used, but it is connected so that one commutator reverses the magnetising circuit while the other reverses the search-coil circuit. The magnetising and search coils are each connected with one of the coils of an ohmmeter, and a magnetic needle will then give a reading depending on the ratio of B to H, or the permeability direct, while the values of H and B are separately given by the galvanometers G_1 and G_2. This method, like the last, has the advantage that only one winding is necessary in the plug; it makes, in fact, a simple universal method

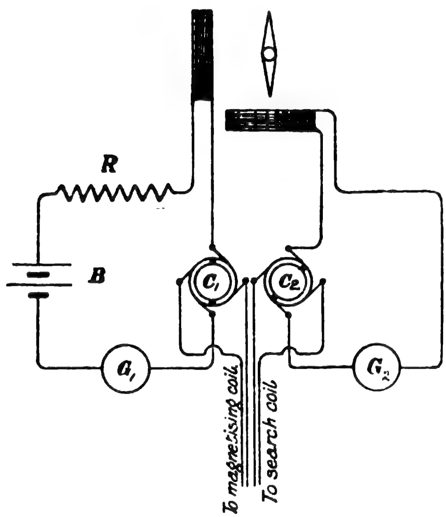

FIG. 7.—Connections for Direct Deflection Test.

of measuring both resistance, and self and mutual induction. Provision must of course be made in this test for running the secohmmeter at a definite speed.

This might also possibly be employed with an alternating current of definite frequency by removing the secohmmeter and substituting a soft-iron needle in the ohmmeter.

COMMERCIAL FORMS OF THE APPARATUS.

Notwithstanding the attractions which the two latter methods offer, I have preferred up to the present to adhere

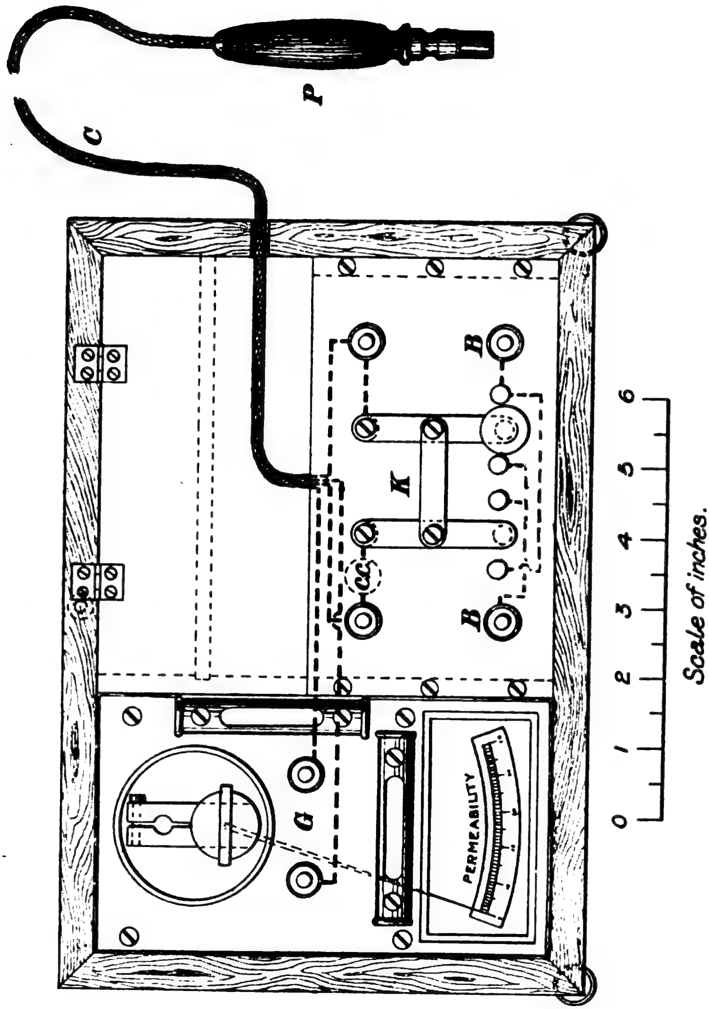

Fig. 8.—Permeability Testing Set.

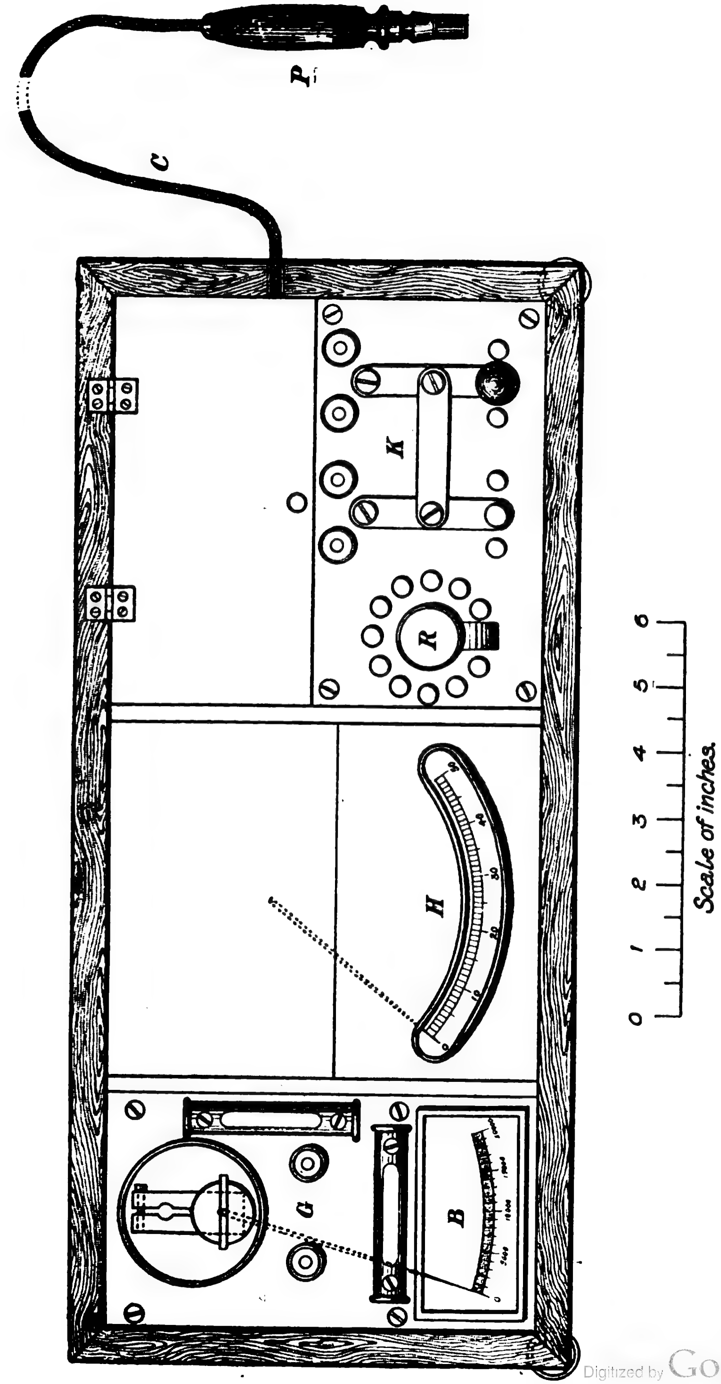

FIG. 9.—Complete Set for Permeability and Magnetisation Tests.

to the simple ballistic test, as it requires only slightly more skill to read the ballistic throw, and the connections are more simple. Moreover, the handle-turning methods do

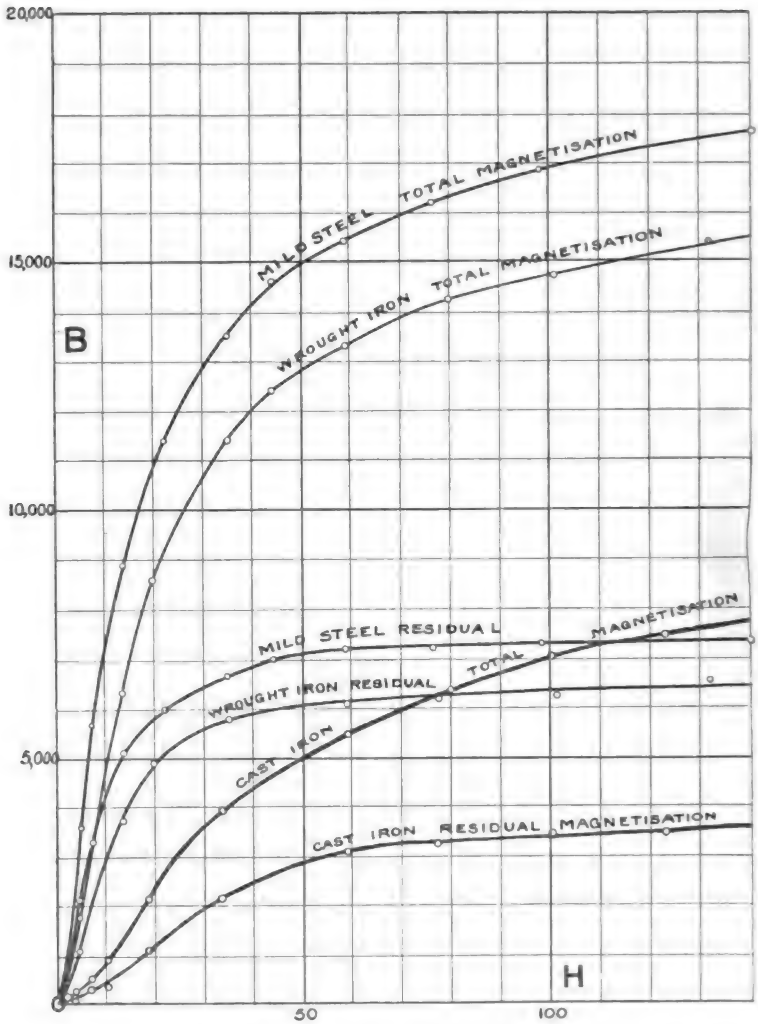

FIG. 10.—Curves of Total and Residual Magnetisation.

not lend themselves well to determining the retentivity of the specimens or their B-H cycles, but simply give the mean B-H curve.

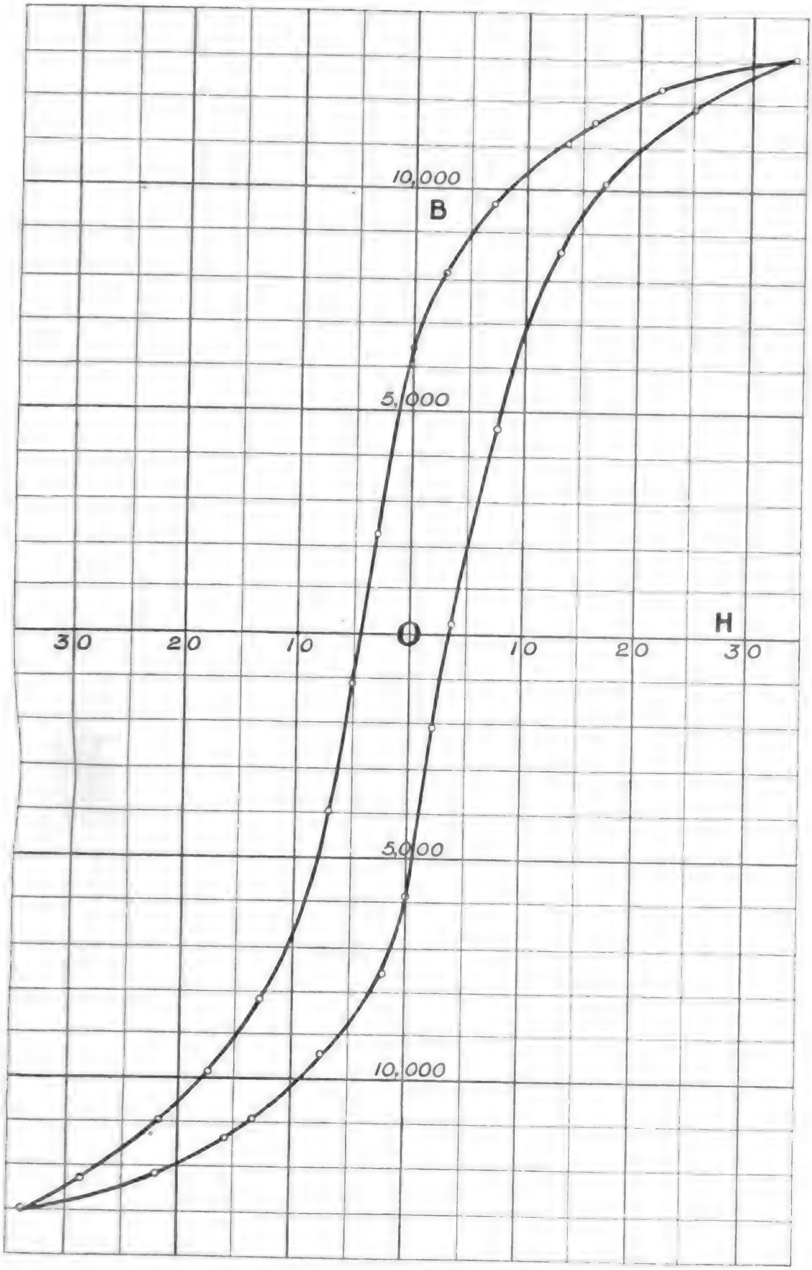

FIG. 11.—B-H Cycle for Mild Steel.

The apparatus is at present made in two forms—the simpler, which allows of the permeability and retentivity being directly read off; and the second, in which the

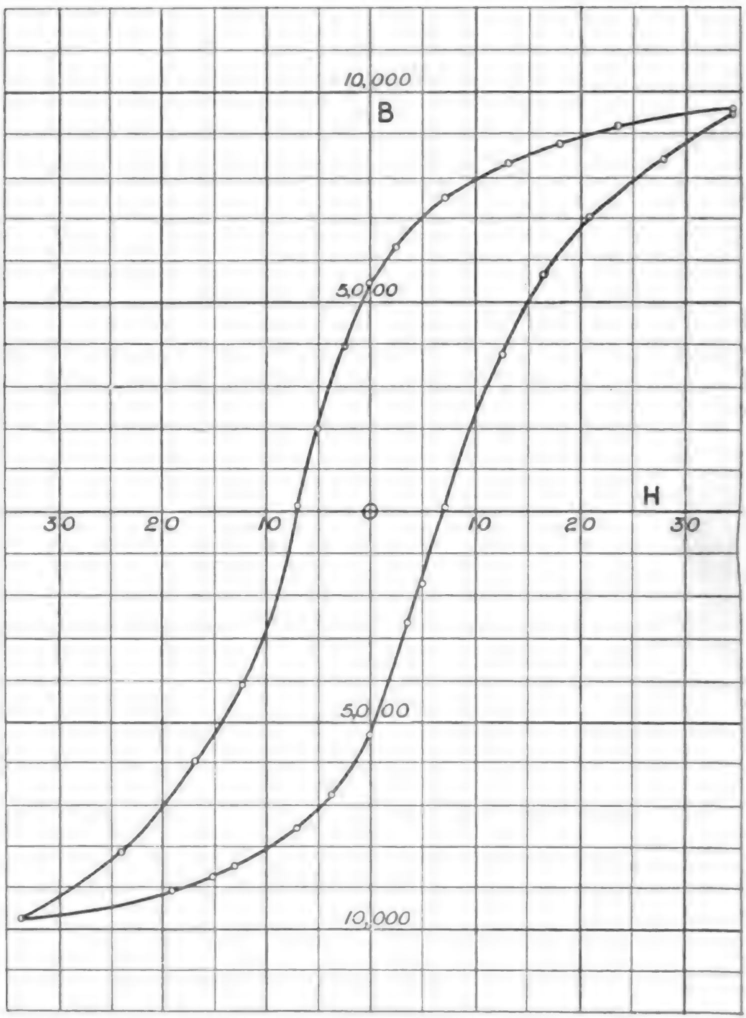

FIG. 12.—B-H Cycle for Wrought Iron.

magnetisation curve and the B-H cycle can also be obtained.

Fig. 8 shows the former of these arrangements. It consists simply of a wooden case 11 × 7½ × 11½ in. high,

containing a battery of two large dry cells, a reversing key K, the plug P which is connected by a long quadruple flexible conductor C to the key K, and to a d'Arsonval ballistic galvanometer G, which is marked directly in values of the permeability. Space is provided under a flap for the plug and drills.

In order to obtain a test, all that is necessary is to drill the specimen, insert the plug and reverse the key. The pointer then swings to the value of the permeability, and if the circuit is then broken and twice the second reading taken from the first, the value of the retentivity is given.

In Fig. 9 the complete set is shown, which differs from the last only in the addition of the milliammeter H and the resistance dial R, increasing the length of the case to 16½ in.

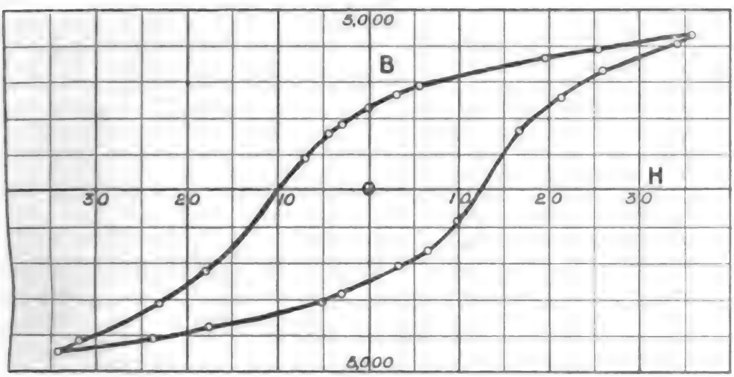

FIG. 13.—B-H Cycle for Cast Iron.

The galvanometer G is then arranged to read the values of B and also the values of μ when H = 100. The total and residual magnetisation curves are obtained as before, while the cycles are determined by observing the throws corresponding to successive variations of the resistance and summing them in the well-known manner. Fig. 10 shows total and residual magnetisation curves for three specimens of mild steel, wrought iron, and cast iron, while Figs. 11, 12, and 13 represent the corresponding B-H cycles obtained in this way. The annexed tables contain the readings actually obtained, while Fig. 2 shows the specimens which were employed.

TABLE I.

Tests of Magnetisation and Retentivity of Mild Steel Specimen.

H.	B.	Deflection on Break.	Residual Magnetisation.	H.	B.	Deflection on Break.	Residual Magnetisation.
5	3,600	750	2,100	58·7	15,400	4,100	7,200
7·5	5,700	1,200	3,300	76·5	16,200	4,500	7,200
13·5	8,900	1,900	5,100	98·2	16,850	4,800	7,300
22	11,400	2,700	6,000	140	17,600	5,100	7,300
35	13,500	3,400	6,700	188·5	18,400	5,400	7,600
44	14,600	3,800	7,000				

TABLE II.

Tests of Magnetisation and Retentivity of Wrought Iron Specimen.

H.	B.	Deflection on Break.	Residual Magnetisation.	H.	B.	Deflection on Break.	Residual Magnetisation.
5·2	1,800	340	1,120	59	13,300	3,600	6,100
7·5	3,300	600	2,100	80	14,200	3,900	6,400
13·6	6,370	1,330	3,710	101	14,700	4,200	6,300
19·7	8,600	1,850	4,900	132·4	15,350	4,400	6,550
35·3	11,400	2,800	5,800	183·5	16,000	4,700	6,600
44	12,400	3,200	6,000				

TABLE III.

Tests of Magnetisation and Retentivity of Cast Iron Specimen.

H.	B.	Deflection on Break.	Residual Magnetisation.	H.	B.	Deflection on Break.	Residual Magnetisation.
2·0	150·0	90		59·2	5,450	1,200	3,050
3·7	260·0	120	20	77·5	6,150	1,470	3,210
7·0	520·0	200	120	100·5	7,000	1,800	3,400
10·2	900	280	340	123·8	7,400	2,000	3,400
18·4	2,100	520	1,060	148·0	7,800	2,050	3,700
33·5	3,900	900	2,100	217·5	8,750	2,500	3,750

TABLE IV.

Magnetisation Cycle of Mild Steel Specimen.

H.	D.	$B = \Sigma D$	H.	D.	$B = \Sigma D$.
+ 34	+ 13,070	+ 13,070	− 33·7	− 680	− 12,960
+ 22	− 800	+ 12,270	− 22	+ 800	− 12,160
+ 16	− 750	+ 11,520	− 16	+ 800	− 11,360
+ 13·5	− 450	+ 11,070	− 13·5	+ 400	− 10,960
+ 7	− 1,400	+ 9,670	− 7·5	+ 1,500	− 9,460
+ 3	− 1,500	+ 8,170	− 2	+ 1,900	− 7,560
0	− 1,750	+ 6,420	0	+ 1,700	− 5,860
− 3	− 4,150	+ 2,270	+ 2	+ 3,800	− 2,060
− 5	− 3,400	− 1,130	+ 3·8	+ 2,300	+ 240
− 7	− 2,800	− 3,930	+ 7·5	+ 4,400	+ 4,640
− 13	− 4,300	− 8,230	+ 13	+ 4,000	+ 8,604
− 17·5	− 1,600	− 9,830	+ 17	+ 1,500	+ 10,140
− 21·8	− 1,100	− 10,930	+ 25	+ 1,700	+ 11,840
− 28·7	− 1,350	− 12,280	+ 33	+ 1,300	+ 13,140

TABLE V.

Magnetisation Cycle of Wrought Iron Specimen.

H.	D.	B = ΣD.	H.	D.	B = ΣD.
+ 34·5	+ 9,600	+ 9,600	− 19·2	+ 700	− 9,030
+ 23·7	− 400	+ 9,200	− 15·2	+ 300	− 8,730
+ 18	− 450	+ 8,750	− 13	+ 300	− 8,430
+ 13	− 400	+ 8,350	− 7	+ 900	− 7,530
+ 13	− 50	+ 8,300	− 3·7	+ 800	− 6,730
+ 7	− 800	+ 7,500	0	+ 1,450	− 5,280
+ 2·5	− 1,200	+ 6,300	+ 3·5	+ 2,600	− 2,680
0	− 850	+ 5,450	+ 5	+ 950	− 1,730
− 2·5	− 1,500	+ 3,950	+ 7	+ 1,850	+ 120
− 5	− 1,950	+ 2,000	+ 12·5	+ 3,600	+ 3,720
− 7	− 1,880	+ 120	+ 16·5	+ 1,900	+ 5,620
− 12·2	− 4,250	− 4,130	+ 21	+ 1,400	+ 7,020
− 16·8	− 1,800	− 5,930	+ 28	+ 1,400	+ 8,420
− 24	− 2,200	− 8,130	+ 34·5	+ 950	+ 9,370
− 33·7	− 1,600	− 9,730			

TABLE VI.

MAGNETISATION CYCLE OF CAST IRON SPECIMEN.

H.	D.	B = ΣD.	H.	D.	B = ΣD.
+ 35·7	+ 4,300	+ 4,300	− 23·8	+ 350	− 4,060
+ 25·5	− 400	+ 3,900	− 17·7	+ 320	− 3,740
+ 19·6	− 220	+ 3,680	− 5·3	+ 700	− 3,040
+ 5·5	− 800	+ 2,880	− 3·3	+ 220	− 2,820
+ 3·0	− 230	+ 2,650	0	+ 320	− 2,500
0	− 360	+ 2,290	+ 3·2	+ 400	− 2,100
− 3·0	− 380	+ 1,910	+ 5·4	+ 400	− 1,700
− 4·5	− 350	+ 1,560	+ 9·8	+ 1,350	− 350
− 7·0	− 650	+ 910	+ 16·6	+ 2,000	+ 1,650
− 18·0	− 3,150	− 2,240	+ 21·2	+ 880	+ 2,530
− 23·2	− 870	− 3,110	+ 26·0	+ 750	+ 3,280
− 31·8	− 980	− 4,090	+ 34·1	+ 720	+ 4,000
− 34·3	− 320	− 4,410			

DETAILS OF CONSTRUCTION AND CALIBRATION.

It will be necessary to say a few words about the construction of some of the parts of the apparatus in order to show what amount of confidence may be placed in the results.

About the drills little need be said except that they must all be made accurately to gauge so as to be interchangeable. In order to make them more easy to centre truly in drilling they are now made with a certain amount of relief in the bottom cutting edges. The form shown does not seem to be truly in conformity with the best principles as to cutting edges, and it is probable that improvements may be effected whereby the time of drilling may be considerably reduced. It is, however, the best of some two or three forms that have been tried.

The plug demands a little more attention. To make the magnetic joints as perfect as possible the plug is very carefully turned to have the same angle as the drill, and the central hole the same diameter as that of the pin. In order, however, to ensure perfect contact, the plug is split longitudinally as will be seen on looking back at Fig. 4, so that on pushing it into place it grips tightly on the pin. Great care is taken to have the bottom edge of the aperture in the plug quite sharp, so as to give certainty in the length of the pin used.

The magnetising and search coils are wound on an insulated brass bobbin split longitudinally to prevent eddy currents. This bobbin is screwed to the end of the plug in such a manner as still to allow of the yielding due to the slit, and the ends of the coils are brought up through the plug as shown.

In order to arrange for a perfectly definite length of specimen a standard piece of steel is kept which has been drilled in the ordinary manner and afterwards cut through near the edge of the cavity so as to expose the interior. The plugs are then turned or ground down until, when they are pushed home in this specimen, the length of the pin exposed is exactly half an inch. Since the value of H is $\frac{4\pi}{10}$ the ampere-turns per centimetre length, the number of turns required for the current in milliamperes to equal H in gausses is $\frac{10^6}{4\pi \times 39\cdot37 \times 2} = 1010$ turns.

In calibrating the ballistic galvanometer it must not be forgotten that, being a moving coil instrument on a small external resistance, the damping is considerable, as indeed is necessary in a commercial instrument. Standardisation of the galvanometer by condenser is therefore unsatisfactory, and the best procedure is to obtain the throw corresponding to a known current and a known coefficient of mutual induction, or with a search coil and magnet previously measured on some other galvanometer.[1] If the search coil is of low resistance and is interposed in the galvanometer circuit the damping will be unaffected. Terminals are provided on the instrument which will allow of this test being made should it be necessary.

[1] The Hibbert Standard Inductor may be conveniently employed.

One other matter should not be forgotten. The small size of the pin causes the gap between it and the search coil to have some influence on the results, as the coil not only cuts the lines passing through the pin, but those in the annular space between it and the search coil. The effect is not large, but it can easily be allowed for by the simple expedient of winding a few turns of wire in the magnetising and search-coil circuits together round a bobbin. A reading is first taken by reversing the current without the iron core. Then if D is this deflection, d_1 and d_2 the diameters of the pin and search coil, the deflection due to the space may be approximately taken as $\frac{d_2^2 - d_1^2}{d_2^2}$ D. The number of turns in the compensating coil is adjusted to give this deflection, in the opposite direction, and thus eliminates the effect entirely. The compensating coil is shown in Figs. 5 and 8 marked C C.

The highest value of H employed is 100, which corresponds to 100 milliamperes of current from the cells. As this is only on for the time of making and throwing over there should not be much trouble with deterioration of the cells.

A clamp is provided for fixing the coil of the galvanometer when not in use, and levelling screws are mounted in the base of the case.

ACCURACY OF THE METHOD.

The forgoing remarks will be quite sufficient to explain all the essential features of the instrument, and it now remains to show how much reliance may be placed in the results obtained.

The writer at first anticipated that owing to the reduction of size of the specimen tested, such great accuracy could not be expected in this test as in those obtained with larger permeameters; but on examination the accuracy obtained was most satisfactory, so much so as to be quite equal to that of ordinary tests.

The first point to determine was of course whether the diameter and effective length of the pin tested could be relied on with sufficient certainty, and careful measurements were made on this point. The effective length of the

specimen was determined by drilling out some holes with the specimen drill and afterwards cutting a longitudinal section of them near the edge. On inserting the plug the interior of the hole could then be seen, and the distance between the bottom of the plug and the end of the pin could be accurately measured with a reading microscope. These measurements were repeated several times, removing and reinserting the plug between each set of readings, and it was found that the greatest variation from the mean did not exceed ·0008 of an inch, which in a length of half an inch means a variation of less than ·2 per cent. In the same way several pins were broken out of the holes after being drilled ; and the greatest variation of the diameter was found to be less than half a mil, or of less than 1 per cent. of the area of section.

It will be seen from the above that the results may therefore be relied on to within 1 per cent. as far as the dimensions are concerned. As before mentioned, special care has been taken in the construction of the split plug that the most perfect magnetic contact is made exactly at the point where the pin enters the plug, as otherwise the effective length might be greater than that measured.

The readings appear to reproduce themselves with the most perfect accuracy. In a deflection of 230 divisions obtained with a certain value of the current in a cast iron specimen a variation of one division in the deflection was very rare, although the plug was taken out and reinserted between the readings, and no particular care was used in replacing it. The perfection of the magnetic joint obtained by the conical fit appears to be all that can be desired, and is certainly better than can be obtained by any ordinary faced joints.

Some fear was at first felt, that the great disproportion between the sizes of the specimen and return path might lead to error, as too low a flux density in the return path would imply a low permeability. Careful tests have been made on this point by turning down the outside of a drilled specimen and taking magnetisation curves between each turning down. The result, however, has shown that the reluctance of the return path may be taken as negligible whenever the external diameter of the specimen exceeds the diameter of the hole by more than an eighth of an inch.

It may be asked whether the drilling of so small a specimen does not injure the pin. No trace of any twisting has been found although frequently looked for, and the consistency with which the results agree even in different drillings, seems to show that the method is reliable.

The wearing of the drill is finally a point of considerable importance, and it is one upon which little experience has been obtained as yet. The experimental drill which was first made up about six months ago and has had a fair amount of use, has never been sharpened and shows no sign of wear.

In conclusion, I can only hope that the method will commend itself to engineers, and that it will be found satisfactory after extended use. So many testing instruments which have been born and carefully reared in the laboratory develop troubles when exposed to the rough conditions of commercial work, that it behoves one to be cautious in predicting the ultimate success of a new one. So far as it is possible beforehand to guard against such difficulties, I think it has been done, and from the experience we have had of the apparatus, under somewhat rough conditions, in the laboratories of the Northampton Institute, during the past six months, I have every confidence in its behaviour.

The sole point upon which experience is required is in the drilling of the specimens. We have never yet found any trouble in drilling specimens of metal such as can be put on a lathe, but for larger castings, etc., some form of portable drilling machine would be necessary. I have not yet used the drill in such a machine, but I am assured by many engineers that no difficulty would be experienced. Should any difficulty be found in getting the drill properly centred, it would probably be well to drill a shallow hole first, with an ordinary twist drill or rose cutter, and any trouble as to the wearing of the drills could be avoided by keeping a standard drill for a finishing cut. There is, however, no reason at present to suppose that such expedients would be necessary, and in any case all trouble would be avoided if small projections were left on the castings or forgings and cut off before drilling.

Finally, I must express my most cordial thanks to my assistants at the Northampton Institute for the help they

have given me in the construction of the apparatus and its testing. I am especially indebted to my Senior Demonstrator, Mr. Jolley, who superintended the construction of the first apparatus, and who has carried through the tests; and thanks are due to Mr. Greenfield, who worked out the form of drill, and Mr. Phillips, who assisted in some of the tests. To Mr. Marinier I am obliged for the diagrams which have illustrated the paper.

ADDENDUM.

It has been noticed from the outset that the magnetisation curves obtained by the permeameter now described, differ from those ordinarily given for iron and steel, in that the rise is much less steep than usual. At the time of sending in the paper it had not been found possible to compare the test taken with this permeameter with one taken by some other method, and no reference was therefore made to this point; but tests have since been made by taking a circular specimen of mild steel, and turning part of it down to a rod half inch diameter, which could be used in an ordinary yoke permeameter, while another portion was drilled and tested by the new method. The magnetisation curve obtained with the new permeameter on this specimen fell considerably below that given by the ordinary method at low induction densities, but at a magnetisation for which H was approximately 100, the curves crossed, and the readings taken with the new permeameter then reached a higher value than that given by the other.

The lowness of the readings at low inductions might be accounted for in three ways—

(*a*) By bad magnetic joint between the pin and plug or between the plug and yoke;

(*b*) By the magnetic reluctance due to the spread of the lines at the point where the pin entered the return path; and

(*c*) By the permeability of the return path being very low, owing to the great disproportion between the sections of the pin and the return path.

As to the first cause, although the shape of the curve would naturally suggest something of this kind, the magnetic joint as before mentioned seems to be perfectly satisfactory. This is borne out by the fact that at high induction densities the new instrument gives higher results than the older one,

which would be accounted for by the reluctance of the return path being less at these high densities, and that the yoke is consequently less saturated.

Tests on the third point were made, as stated on p. 302 of the paper, by drilling a cylindrical specimen of considerable diameter, taking a magnetisation curve and turning down the outside of the specimen until the return path was considerably reduced. The magnetisation curve was again taken, and this process was repeated three or four times. Had there been a high reluctance of the return path owing to the low density of the flux, it should have been found that on first turning the outside of the specimen down the magnetisation curve should have been made steeper; but this was not found to be the case. Until the specimen was so reduced that its exterior diameter was only about ·2 inch greater than its internal diameter very little effect could be seen on the magnetisation curve, while on further reduction of the external diameter the curve dropped lower, showing that the reluctance was then increased.

The cause of the difference between the readings with this permeameter and the ordinary methods must therefore be sought for in the effect of the ends of the specimen, and this is to be anticipated since the length of the specimen is only five times its diameter, instead of between twenty and thirty times its diameter, as in the ordinary yoke permeameters. It should not be forgotten, however, that the ratio of length to area, or the reluctance to the pin, is very nearly the same as in the ordinary specimen, so that the difference is not so serious as at first sight would appear. The effect of the ends of the specimen can however be allowed for by experimental methods, such as that employed by Professor Ewing, and the scale of the galvanometer reading H can be calibrated to suit this. This makes the instrument less easily checked than it would otherwise be, but the correction is a fairly definite one, and is the same for all instruments if the dimensions of the plug are standardised.

An obvious method of eliminating this effect would be to increase the length of its pin or diminish its diameter. The former course seems inadvisable, as it would considerably restrict the range of usefulness of the instrument, while any reduction of the pin beyond the dimensions given would make the drilling far too delicate an operation

to be undertaken under ordinary works conditions. I should, therefore, prefer to adhere to the dimensions before stated for commercial work, correcting the scale as mentioned, while for work where the highest accuracy is required I have tried a drill turning out a specimen one-twentieth inch in diameter, and in which the reluctance is therefore increased four times the value. It seems perfectly possible to obtain specimens with this drill, and where accuracy is required and more time can be given there is no doubt that it can be used.

The main point, however, from the practical point of view, and this instrument is essentially intended for practical engineering use, is whether the instrument will give readings which will indicate the quality of any casting or forging, and whether reliance can be placed in the results so obtained. There seems to be no doubt that this is the case, and further, that when the scales are properly prepared the readings of the instrument will give a very close approximation to the absolute values of the various quantities to be measured.

Mr. Evershed.

Mr. S. EVERSHED: I am sure you will all agree with me in admiring the very practical apparatus which has been brought before us to-night. I think at first sight one feels a little discouraged by the complexity of all apparatus for testing iron, but I do not think we ought ever to expect to get anything very much simpler than the ordinary ballistic galvanometer test, especially when carried out by an apparatus such as we have before us, made especially for that purpose. We are rather apt to compare such tests with other very simple things, and I think we ought to congratulate Dr. Drysdale on having brought us something which is, at all events, as far as preparing the specimen is concerned, tantamount to testing a piece of cheese. But although I admire the apparatus very much I am going to criticise it a little.

The first essential in all ballistic tests is that the test should be carried out in such a manner that you are certain to obtain accurate results, and that is one of the drawbacks to all the yoke methods, which always involve joints. Joints possibly do not lead to trouble in the Northampton Institute, and they do not give any trouble in Cambridge, I am told; but I find by experience at our works (and I expect it is the same in many other works) that they do lead to trouble. In the plug there is a conical joint which one may pass over; its area is very large, and probably it makes a very perfect joint. But the pin where it passes into the plug necessarily leaves a very small air-gap; and I think the evidence of the curves themselves is sufficient to show that the air-gap has a practical influence on the results. I will draw your attention to figure 12, from which you will notice that the residual

induction appears to be something of the order of 5,400 for wrought iron. That, in my experience, is an extremely low figure. It is more probably due to the fact that the joint has a certain amount of resistance. If you test a complete ring turned out of wrought iron you will very rarely indeed find the residual induction less than about 9,000. Dr. Drysdale has given one explanation of the fact that these curves are not the same as those obtained by ring methods; but I hardly think his explanation is sound, because any explanation which has to do with an error in the calculation of the magnetising force of the coil, cannot apply at a point where the magnetising force is zero; and I think that in all probability the joints do account for a certain part of the apparently low permeability of the samples of iron. The same remark applies to mild steel, but one cannot be so positive about that because mild steel varies very largely. Mr. Evershed.

I quite agree with Dr. Drysdale in shunting the secohmmeter. It is not an instrument which is safe for use in testing iron, because you are really using an alternate current to magnetise the iron, and you cannot possibly tell how much of the apparent self-induction is due to eddy currents, or, in other words, to the fact that the iron is a conductor and acts like a secondary circuit. I think one must rely on the ballistic galvanometer. But I want to point out one other source of error in this particular method of testing—one which is perfectly easily corrected by making a small alteration in the connections of the instrument. I gather from the paper that Dr. Drysdale's method is to take deflections which give the differences in the induction corresponding to successive increments in the current. I think it is something like ten years ago that Mr. Vignoles and I showed that that method led to curves which had too small an area, especially in testing solid specimens of iron. It does not occur quite so much in the yoke sample as it would in a ring; but still it is always there. During the time you are preparing to take the next deflection, the magnetisation of iron (as Professor Ewing showed long ago) changes as the molecules turn round and get into line with the others. The result is that your next deflection does not start at the point where you left off, but from a point higher up. The only way to get over that of which we knew at the time when we made our experiments ten years ago was by winding two primary coils, and always taking deflections from one point. For example, one could take the whole deflection from the negative maximum by breaking the current in one of the primaries. You take the whole deflection at once from the negative maximum to any point, and before proceeding to the next point you carry the iron right up to the positive maximum and down to the negative maximum—that is, you begin again every time on the same point, and in that way you get curves which really represent the proper hysteresis cycle. Some years afterwards you may remember that we showed in a series of articles in the *Electrician* that the area of the curve obtained in that way agreed within the errors of observation with the hysteresis loss on alternate currents of a fairly high frequency. I do not think that you could have a better test than that.

To go back to the joint, Dr. Drysdale is no doubt aware that

Mr. Evershed.

Professor Ewing in his work on magnetisation goes into the question of joints and the amount of pressure to be applied to a joint practically to eliminate its effect. I think a little study of Professor Ewing's work will lead Dr. Drysdale so to improve his plug that the joint-effect which is noticeable in the curves will be entirely eliminated. But it seems to me that these are matters practically of detail. I feel certain that Dr. Drysdale is on the right track, and I heartily congratulate him.

Mr. Glazebrook.

Mr. R. T. GLAZEBROOK: Dr. Drysdale has given so very clear an exposition of the method of his instrument and of the results obtained by it, that he has not really left very much room for discussion. With Mr. Evershed, I feel considerable doubts, however, as to whether Dr. Drysdale has got over the effect of the joint. First, the extreme smallness of the pin and the fact of a joint round the top end of the pin (considering that slight variations there will produce very large effects), must, I think, constitute a distinct weakness in the method as it has been explained to us at present. Then, I do not feel quite convinced by Dr. Drysdale's explanation of the method of correcting for the small air-gap between the pin and the search coil. He did not happen to mention the amount of that correction—possibly it is so small that my criticisms hardly apply—but, as I understood, he works it out practically on the assumption that the distribution of the lines of force in the air-gap between the air and the search coil is the same when the iron is there as when it is away. I feel grave doubts as to whether that is the case. My impression is that the distribution of lines of force in that narrow air-gap is considerably modified by the presence of the iron. And then there was another point which I think perhaps affects the whole method. The want of an instrument such as Dr. Drysdale has put before us is very fully realised by all who have worked at all at this matter, and I suppose the idea of endeavouring to get a search coil into the interior of the iron casting is one which must have occurred to many people; I think we may congratulate Dr. Drysdale on the way in which he has carried out that idea. But I do not feel certain than an instrument which takes the coil to a depth of ⅝ of an inch at most into the interior of the casting, really gives us the information that we wish. He said that in some cases where it was inconvenient to get into the casting you could have rods or lumps put on the casting and cut off; but have you any security that such lumps or rods have the same nature magnetically as the interior of your casting? or even if you do not use lumps or rods, have you any security that the shell of your casting through ⅝ of an inch of its surface is really the same as the iron in the interior? If I might suggest to Dr. Drysdale a sort of test experiment that occurred to me as he was reading his paper, it would be this—that he should take a casting of considerable size, that he should bore holes over the surface of that casting and get a series of tests of the surface; then that he should cut through the casting and make a series of tests of the interior on the new surface so obtained. He would then be able to show to what degree of accuracy the instrument would work, or how far it was satisfactory to make a test in that ⅝ of an inch

of the surface. Some test of that kind appears to be needed before we should feel satisfied that the method will give us the information that is needed, as I understand, by engineers when they are constructing large machines and are dependent on the nature of the iron or steel in the interior of large castings. Mr. Glazebrook.

Mr. W. B. ESSON: On the occasion when Messrs. Lamb and Walker's paper was discussed, I believe I said that what was required was some kind of instrument for testing iron where you merely turned a handle and got your reading. What I intended to imply was that we wanted simplicity; but if my unfortunate remark about turning a handle induced Dr. Drysdale to produce the instrument shown in diagrams 6 and 7 I am very sorry, because the instrument shown in figure 8 is so much superior in every way that it is really a pity he took the trouble to devise the other two. A good deal has been said about difficulty with the joint; but this is important merely with reference to the point from which you regard the instrument. If you wanted to make scientific tests, laboratory tests, then, of course, the joint is an all-important matter, but when dealing with large castings what we really want to make are qualitative tests. We want, in most cases, to compare standards with castings sent in for use, and simply to tell whether the castings come up to the standard. From that point of view the joints have little importance. The great point is, to insure that the pins will always be of exactly the same diameter. I foresee that there may be considerable difficulty with the drilling; but apart from that I cannot see any objection to the use of the instrument. With regard to the testing of castings in bulk, I think we must give up the idea of being able to do that. The process adopted up to now has been to test sample bars; and in testing those there has been no guarantee, of course, that they would be the same as the bulk. But Dr. Drysdale's instrument is really a considerable advance because there is a great deal more likelihood that the properties of the casting as a whole will correspond to the specimens at the $\frac{5}{8}$ inch depth, than there is that they will correspond to those of a mere bar cast quite separately from it. Mr. Glazebrook naturally wants perfection, but even if you bore a casting through and through and find that the tests so made correspond with the tests made at a depth of $\frac{5}{8}$ of an inch, is there any guarantee that the next casting tested would give the same result, and that it would not be full of blow-holes in the middle? Mr Esson.

I think the instrument devised by Dr. Drysdale will, to use a rather hackneyed expression, "meet a long-felt want." It is very pretty indeed; he has put it in a very practical shape as shown in figures 8 and 9. What we really want is, as Dr. Drysdale says, not to carry the curve completely through; because it so happens that in castings to which his instrument is applicable we do not care very much about the hysteresis. What we care about is the permeability, and to know what that is within a comparatively narrow range. His instrument is excellent for that purpose. For testing hysteresis loss we have Ewing's instrument. Where hysteresis loss is all-important, the iron or steel is always in the form of thin bars.

Mr. W. M. MORDEY: There is no doubt as to the great importance Mr. Mordey.

Mr. Mordey. of this subject, and I am very glad indeed to see it tackled in such a pretty and, I hope, successful and practical way. When Professor Ewing read a paper on a permeability measurer two or three years ago I gave examples of the difficulties that dynamo makers experience in not being able to test the iron in bulk before working on it. I instanced two large machines exactly alike, externally and internally, as far as one could tell. The castings were made by the same people at the same time, and yet the difference of the excitation of these two machines was 70 per cent. But I am afraid that if Dr. Drysdale's instrument is a success, as I hope it will be, he has destroyed the last line of defence of the electrical designer. What are we to say when our designs do not come out quite right in the matter of speeds, etc? We shall not be able to turn round and blame the iron. The author says it is probably sufficient to know the value of the permeability for one value of the magnetising force. To go back again to that same occasion when Professor Ewing brought before us an instrument the sole object of which was to measure the permeability at one value, I pointed out that I did not think he would long be satisfied with such an instrument, as one value was not sufficient to tell us what the whole curve was like. I remember some one else in that discussion—I think it was Mr. Hawkins—showed that three curves of iron crossed at one point but were quite different in other parts of the curves. I think that is sufficient to show that Professor Ewing was right in giving up the instrument which he then described to us, and bringing out, as he has done since, an instrument which measures the permeability at a number of points. I have one or two criticisms that I should like to make of the author's method—probably the points have already received his attention. One of them is that a great deal very often depends upon the physical state of the iron. I am afraid the process of tooling will lead to quite incorrect results, by affecting the physical state of the iron, unless some process of annealing is adopted afterwards. It may be said that as you will always get the same kind of effect, you will get, at any rate, comparative results, which need not exactly represent the permeability but which may be useful when some constant is applied to them obtained by comparing the results obtained with those from the completed machines. Then, of course, there are the difficulties which have been mentioned as to the variation thoughout the mass of the metal. The local variations of permeability and resistance in iron are sometimes considerable. In aluminium, for instance, you get the same sort of effects. I daresay many of you have noticed the irregular speed of a motor meter with an aluminium disc—it seems to be due to little local differences of hardness causing variations in the resistance. The author of the paper, I think, is too modest in describing the system as one suitable only for measuring in bulk. As the bulk required is really very small, it might be very well used for measuring small samples quite as well as large ones. Personally I must express a preference for weighing methods. It seems to me that Professor Ewing is probably right in having adopted weighing methods. After all, the pull one can get with a magnet is a very tangible thing; and if there is nothing to read but the current and the position of a weight

on a beam there is as great simplicity as can ever be expected in any apparatus for such a purpose as this. However, I congratulate the author on this instrument, and I hope it will be found very useful in this art of ours. Mr. Mordey.

Dr. R. M. WALMSLEY: I wish to congratulate Dr. Drysdale, who is my own chief assistant, publicly upon this instrument, which, in my opinion, may lead to a revolution in commercial methods of testing iron. I am very pleased to know that the practical men who have preceded me in the discussion have united in a chorus of approval, only interfered with by criticisms which refer to details. I had noted four points for criticism, but every one of these has already been dealt with. I would like, however, to emphasise one point made by Mr. Esson, namely, that although the curves may not be those which you get with careful laboratory experiments—and here I may say I quite agree with Mr. Evershed that the effect is probably an air-gap effect, the slope of these curves being far greater than it ought to be according to what we are accustomed to expect from iron—when we are testing with solid plugs like these, we are not testing iron in the shape of plates which are to be used for armature cores or for the cores of transformers, but we are testing the iron in the shape in which it is to be used in positions where it is not to be subjected to rapid reversals of magnetism. Whether, therefore, the hysteresis curve is too small or too great is, as far as this method of testing is concerned, a matter of very small consequence. Dr. Walmsley.

The conical shape of the plug has been devised not so much for the purpose of getting a large contact surface on the outer surface of the cone as for the purpose of getting a good grip upon the smaller surface inside. The plug is split, and, as it is driven home, it grips down on the pin, and it is on that surface that the air-gap occurs and not so much on the other larger surface—the contact between the outer iron and the plug. I should also like to emphasise the point that the whole magnetic circuit of this test, except the small amount of iron in the plug, is of the material under test. There is only a small quantity of foreign material in the circuit, and in this respect the method differs from other methods of testing which have been devised on the yoke system.

Mr. S. F. WALKER: I should like to raise a practical point on the instrument shown in figure 8 which I think Dr. Drysdale has not looked into. It is a thoroughly practical instrument, and I entirely agree with the author of the paper in leaving out resistances. The instrument has to go into a workshop and to be handled by men who should not be troubled unnecessarily with resistance coils, contacts, and the like. But in leaving out the resistance coils you are dependent upon the E.M.F. of your battery being absolutely constant. I never yet knew a battery, however, which would keep its E.M.F. absolutely constant for many hours, or even less, as you want it to be here. I would suggest, therefore, that a scale might easily be formed, giving different values for different values of the E.M.F. of the battery; it is then a simple matter to take the voltage of the battery before you start your test and read off your scale. Mr. Walker.

Mr. Atkinson.

Mr. Ll. B. Atkinson: It is now some two or three months since I had the opportunity of seeing one of the first of these very ingenious instruments which was then, I believe, in its initial stages. At the time I was extremely sceptical of the results that were possible from such an instrument. Dr. Drysdale has removed much of the doubt that then existed in my mind; but the point that does occur to me with regard to the paper is that he has proved everything except that the instrument gives the permeability of the specimen. I have only had the opportunity of going quickly through the paper and of hearing his lucid explanation of the instrument, but there appears in the paper to be no direct comparison of the result obtained with this instrument with those more ordinary methods to which we are accustomed—either the ordinary permeameter with the bar and large blocks, or the coil and circular ring. Possibly he will be able in his reply to inform us that he has made such tests and that the results are coincident; but the fact remains that the curves he shows us bear out what has already been indicated—that the air-gap has, at all events in the earlier part of the curve, a very considerable effect on the result. Notwithstanding this criticism, there is no doubt that the instrument has a great field for practical engineers wishing to determine rapidly whether there are those very wide differences, at all events between specimens of iron, to which Mr. Mordey has alluded. The methods shown in figures 6 and 7 devised to enable engineers to turn a handle do not appeal to me at all. I am quite confident, as Mr. Evershed has pointed out, that the results will be largely affected by the conductivity of the specimen, which may or may not have anything to do with its magnetic properties. The return path is also to some extent an admitted factor in the results which he will get.

I would like to suggest that two drills should in all cases be provided, one a roughing-out drill, and the other a finishing drill which is only to be used when taking a final cut. It is the experience in making all gauge work, that it is absolutely necessary to rough it out first, and then to finish it with a tool that is not going to have any ordinary wear upon it.

Mr. Joyce.

Mr. S. Joyce: All manufacturers of dynamos and electrical machinery will thank Dr. Drysdale for the instrument he has put before us. It has been somewhat severely criticised by Mr. Evershed and other speakers; but, from what Dr. Drysdale states, the different observations in a test vary so slightly that the effect of the air-gap, which is no doubt indicated in the curves, must be of a permanent nature, and can therefore be allowed for; so that the information that manufacturers really want can be obtained, namely, a comparative value obtained with some well-known tested sample. We are not going to take hysteresis cycles for masses of cast steel.

I should like to say that I am afraid the sizes of the steel employed in the shells of some motors do not admit of being tested in this way, because the shell of the motor generally is so thin that the size of the hole required cannot be obtained in it. After all, the trouble which we generally experience is not in this part of the structure so much as in the poles, which may contain a mass of carbonaceous matter,

wanting in permeability and quite unreachable by the drilling. However, as a dynamo maker, I congratulate Dr. Drysdale, and thank him heartily for having brought before us this exceedingly practical apparatus. Mr. Joyce.

Professor J. PERRY: We all congratulate the author on his very beautiful instrument, but I want to ask him a question on a point which he has probably thought out. There is a pin produced by the drill. Why not cut that pin out, turn it up a little smaller, and then test it in a small permeameter? The longer you make the pin and the smaller in diameter, the more you will get rid of all difficulties about the resistance of joints; moreover, you can take a great number of specimens, with less waste of material, all over your casting. Prof. Perry.

Prof. F. G. BAILY (*communicated*): In the instrument designed by Dr. Drysdale a new line has been struck, in which originality and boldness are equally conspicuous. To obtain magnetic measurements of the metal in the block is undoubtedly an achievement of practical importance, even though the results obtained may not prove to be of extreme accuracy, and while I venture to criticise some points, I do not wish to imply that the instrument is of no practical utility. Prof. Baily.

The use of a ballistic galvanometer in a portable commercial instrument is open to the objection that the observed swing is a function of the damping. In the laboratory this is of little importance, since the decrement may easily be measured, or the calibration, carried out at the time, may be arranged to allow for damping. But when an instrument is sent out into the world with a definite scale, any change in the damping will introduce an error. Now the friction of the pivots is a very variable quantity, and while in steady deflexion instruments friction is immaterial, so long as it is less than a certain not very small quantity, in the present instrument the difference between a fairly easily and a very easily swinging coil will considerably affect the readings, rendering necessary a correction table and a determination of decrement, or the adoption of one of the direct deflexion methods proposed by the author.

The second source of inaccuracy is more serious, and is the result of the very short magnetic circuit. All who have spent time in designing magnetic measuring instruments will know what a host of possible errors haunt the apparatus. Length of magnetic circuit is the only certain alleviation for many of them, and the present instrument disdains this method without introducing any other. What is the reluctance of the part of Dr. Drysdale's circuit at and beyond the section where the pin meets the solid? Until he knows the magnetic properties of the sample, he cannot tell, and even then the calculation is laborious if accuracy is required. His experiment of reducing the thickness of the return path tells us nothing, for the extreme reduction left an area sixteen times greater than that of the pin, and the reduction did not in the least affect the part just beyond the exposed part of the pin. A reference to Prof. Ewing's paper (*Proc. Inst. Civ. Eng.* vol. cxxi., part 4) gives experimental proof of the magnitude of this correction, and proves that it is not constant for the same specimen under different conditions, nor is it constant for different specimens under the

Prof. Baily. same conditions. At an induction of 10,000, with a ratio of length to diameter of specimen slightly greater than that used by Dr. Drysdale, the error in the value of H was 45 per cent. with soft iron, and 27 per cent. with soft steel. Judging from the figures given in the paper I do not find that Dr. Drysdale has made any allowance for this at all. He might at least have taken an average figure for it, and reduced the error by a considerable amount.

Another error of small size will be introduced by the small diameter of the pin. There will be a certain thickness of somewhat modified metal, caused by the pressure of the tool. The thickness will depend on the bluntness of his drill, and in any case the affected material will form an appreciable part of the small area of his pin.

While it may be objected that these criticisms are based on theory, I may reply that the scale of his instrument is also theoretical. The tests that are shown do not prove anything about the instrument, except to show that the ballistic galvanometer works well. There is no proof that the readings are the real values of B and H. We cannot take the specimen and test it independently by another method, because it is too small. If the inventor will show us magnetic curves of soft iron, cast iron and mild steel, obtained from large annealed rings by a search coil and ballistic galvanometer, and the same curves obtained by several borings in these same rings and the use of his instrument, both sets of curves expressed in c.g.s. units, all independently calculated and with no correction tables, then we may safely believe in his apparatus; but I shall be agreeably surprised if there is not an error as large as 10 or 15 per cent. in parts of one or other of the curves with the present form of instrument. There is no doubt that the idea is very ingenious and the details beautifully designed, but I should hesitate to condemn a sample of iron on its evidence alone, until it has been more rigorously tested. In spite of these objections, however, the apparatus will give us an approximate knowledge where previously we had no means of obtaining any at all, and it should therefore be of considerable utility.

The President. The PRESIDENT: Dr. Drysdale has given us a very interesting paper. He has placed it before us in a most interesting manner, and I feel quite satisfied that he will be very grateful for the opinions that have been expressed in relation to his invention. I will ask Professor Drysdale to be kind enough to reply.

Dr. Drysdale. Dr. DRYSDALE in reply (*communicated*): I regret that time did not permit of my giving detailed replies to the various speakers at the meeting, but now take the opportunity of doing so. At the outset, however, I may say that a number of the points raised in the discussion concerned the behaviour of this instrument as compared with the ordinary permeameters. It was found impossible to get much evidence on this point before the setting up of the paper, but since that time a few experiments have been made, and a short account of them was handed in before the commencement of the meeting, and will appear when it is finally printed.

In reply to Mr. Evershed, the question as to the perfection of the joint is, of course, an all-important one, but I am perfectly confident

Dr. Drysdale.

that any one who has felt the fit of the pins in the plug, and the grip which is produced when the plug is forced into the cone, will be quite satisfied that the joint is far more perfect than in almost any other permeameter. Although the specimen is short its small area renders its reluctance about the same as that of the test rods usually employed, and the fact that only one joint is made with the specimen, the other plug joint being of very great area, makes the magnetic circuit exceedingly good. In proof of this, as I have before mentioned, the magnetisation curve obtained with this permeameter rises higher than that taken with a Hopkinson yoke at high induction densities, although it is lower at the outset. This effect could not possibly be produced if an appreciable air-gap existed. Mr. Evershed instances the amount of residual magnetisation in the wrought-iron specimen as evidence in support of an air-gap being present. I have just looked up some tests of a wrought-iron specimen taken with a Hopkinson yoke some time before the new permeameter was devised, and I find that the residual magnetisation is slightly less than that given in Fig. 11. I may say that the specimens employed in each of these tests were of very soft iron, and I think it probable that Mr. Evershed's own tests must have been with some more retentive specimens.

A further objection that Mr. Evershed raises is to the use of a secohmmeter, in that it produces eddy currents in the specimen. This point has of course not been overlooked, but it must be remembered that as the specimen is of such small dimensions the eddy current effect is exceedingly small, and so long as the secohmmeter is not run at an excessive speed there would probably be little error from this cause. It is for this reason that I have felt justified in employing secohmmeter and alternate current tests which would not be allowable if the specimen were of larger area. The remaining point which Mr. Evershed criticises is the method of getting the hysteresis cycles by a summation method. I attach little importance to the obtaining of the hysteresis cycle in commercial work, as the cases in which this permeameter will be used are for specimens which are not subjected to varying magnetisations; it was rather as a matter of interest that I showed they could be obtained. Although, however, I am aware of the creeping effect to which Mr. Evershed alludes, I am inclined to think that the reduction of the diameter of the specimen reduces this error considerably, and this view is to a certain extent strengthened by the fact that the cycles which have been obtained close very perfectly, although the steps taken are by no means regular. If viscous changes occurred in the specimen to any extent, it is more than probable that the cycle would not be perfectly closed unless the steps taken in increasing and diminishing the magnetising force were the same.

Dr. Glazebrook also expressed some doubts as to the perfection of the joint, but my remarks on Mr. Evershed's questions will apply to his criticisms.

With reference to the matter of the compensating coil, of course Dr. Glazebrook is perfectly correct in stating that the assumption made in finding the turns on the compensating coil is not scientifically allowable. I was careful to state in the paper that it was only an approximate

Dr. Drysdale.

method, but Dr. Glazebrook will see that this matter is only of theoretical interest, when I tell him that the whole difference between the true values of the induction and the observed values due to the inclusion of the surrounding field is not more than 5 per cent. at the outside.

The next point which Dr. Glazebrook mentions is of course of exceedingly great importance, viz.; as to the uniformity of the material tested. There is no question that different parts of a large casting may differ to a considerable extent in their qualities, especially if it has required more than one pouring to produce the casting. In this case, however, there is no reason why more than one drilling should be made, as the value of the casting would justify such a course. We have not yet had time to investigate the interior of the casting in the manner that Dr. Glazebrook suggests, but we have tried several drillings on the same specimen, with the result that the values of the permeability obtained have not differed as a rule more than about 2 or 3 per cent. Some of these drillings were made at the edge, and some near the centre of a somewhat thick plate.

I am glad to find that Mr. Esson is so favourably disposed to the instrument, and that he, as well as Mr. Mordey, has practically shown how exceedingly great the differences are that are practically met with in the quality of magnetic materials. While we have variations of 70 per cent. in the excitation, as Mr. Mordey mentions, on account of the variation in material, matters as to the possible influence of small joints or even of comparatively small variations in the quality of various parts of the casting are of small importance. It is perfectly clear that where such large variations occur even one single drilling would most probably give a very fair indication of the general character of the casting, and I am quite confident that if the results obtained by this instrument are only correct to 10 per cent. they will be of immense assistance in practice.

Mr. Esson appears to be very frightened by the formidable appearance of the secohmmeter connections. Although personally I do not care for these methods, it would be quite possible to include these in a simple test set. The sole real objection to them is in possible trouble with the contacts.

As to the effect of the tooling of the pin on the result, this is no doubt an important matter. There would be no difficulty at all in annealing the pin in place by a blow-pipe flame if required, but a careful study, both microscopically and otherwise, of the pin, has convinced us that practically no strain is given by the cut. I do not think that we shall have any difficulty in standardising everything so that the sizes will always be perfect.

Mr. Mordey seems to prefer a weighing method of getting the observations: I do not think it would be advantageous to apply that method to this test, but it might be done. He also asks whether we could not drill a cylindrical hole only without the cone, but I think, as other speakers have realised, that the cone is the essence of the matter. I do not think you will get a good fit either on the pin or the outside of the plug without the conical fit, and the drilling is made but slightly more difficult thereby.

A further point Mr. Mordey raises is an interesting one, as to whether the permeability at one point, such as would be given by the smaller testing set, would be sufficient. Although Mr. Mordey quotes instances of curves which cross one another, this, I think, must be a somewhat rare experience, and I fancy in this case that, although the curves cross, the difference between the values at other parts of the range cannot have been very great. For ordinary commercial purposes I am inclined to think that the test at one point would be sufficient. Dr. Drysdale.

Dr. Walmsley points out, as I have before remarked, that the cone in the plug is for the purpose of giving a firm grip of the pin, and not for giving any additional area of contact. It is, however, also of service in getting an accurate fit, the contact between two cones being probably the most perfect that can be obtained, as is evidenced by resistance boxes.

Mr. Walker raised an important point as to the constancy of the battery. In the larger set, where both H and B are measured, this is a point of small importance, as no variation of the cells affects the accuracy of the reading: in the smaller set, where no ammeter is provided, any falling off in the cell would of course mean error in the results, but this is easily obviated by having a low resistance shunt in the battery circuit and a two-way switch which enables the galvanometer to be connected to the shunt. The current given by the battery can then be tested at any time, and if necessary, just before and just after a ballistic throw is taken; this arrangement will be provided in future sets. It was at first proposed to employ accumulator cells, which, when fully charged, give a very constant E.M.F., but the difficulty of having these charged and kept in good condition seems to me a considerable objection to them, and I think that the dry cells, if checked in the way I describe, will be perfectly satisfactory. Provision will of course be made to allow of the renewal of the cells when necessary.

Mr. Joyce, as a dynamo maker, realises that the most important matter from the practical point of view, is to be able to ascertain whether the permeability of the specimen is up to a standard or not. I do not admit that there is any appreciable air-gap at all in the magnetic-circuit, but so long as any end effects are constant, the indications of the quality will be satisfactory. Of course if there is a large mass of inferior material in the centre of a casting the readings would not be representative, but in that case the remainder of the metal would in all probability be spongy, and this would be detected either in drilling or testing.

As to the thin shells of machines, I have already stated that there would be no difficulty in having such castings made with small projections for testing.

Mr. Atkinson objected that I had not given any direct comparison of the results of the new method with those obtained by orthodox tests. In the addendum to the paper which I have above referred to, I have given a statement of the effects observed up to the present, but I am anxious to have further evidence before coming to a perfectly definite conclusion. There seems to be little doubt that at the bottom of the range the new permeameter gives results which are too low,

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while at high saturations the ordinary yoke methods give too low results ; at inductions for which H has a value of about 100, the two methods give practically identical results.

As to the use of two drills, which Mr. Atkinson advocates, I have referred to the possibility of doing this in the paper. I am inclined, however, to think that if the whole operation can be performed with one cut it will be more satisfactory, not only from the point of view of time, but because it is exceedingly difficult to get a second drill accurately centred with the roughing drill, and unless the centring in this case is exceedingly perfect there is a chance that the pin will be sheared. In our experience the cut given by the single drill has been so perfect as to leave nothing to be desired.

Professor Perry asks why the pin should not be simply drilled out and placed in a Hopkinson yoke such as I exhibited. This was what that yoke was intended for : the arrangement was made to suit an ordinary 10 B.A. cutter, the rod could be drilled out and placed directly in the yoke. I have no objection to this process, but think that the one I proposed will be found more convenient in practice, and the yoke method has the disadvantage that you have two joints on the small pin, instead of one as in the plug form. It is also to some extent an advantage to have the return path as much as possible in the bulk of the metal, as any influence of the quality is made still more manifest.

Professor Perry thinks that it might be an advantage to turn down the pin and anneal it before placing it in the yoke, but as I have before said, the metal does not seem to be in any way injured by the drilling process, and no turning could make the fit more accurate than that obtained with the drill. In order to make the reluctance of the pin greater, and the effects of the ends or air gaps less, I have tried a pin of $\frac{1}{20}$ inch diameter. Professor Perry approves of this course, but he must remember that the drilling is thereby made much more critical, and moreover small flaws in a casting might render it impossible to get any results at all. I think the $\frac{1}{20}$ inch drill may possibly be of service in investigation work, or possibly in consulting work, and I am therefore having such plugs and drills further experimented with.

Mr. Esson, on the other hand, has since told me that he would have no objection to a drill twice or three times the size ; in fact, for large work he would much prefer it as giving less chance of breakage of either the pin or drill. I am very glad to hear this, and will arrange to have larger drills and plugs made ; it is, of course, quite easy to arrange by resistances, etc., that the readings given by different types of plugs would be the same.

In reply to Professor Baily, the first point that he raises is as to the variation of the damping in the galvanometer. As I specially called attention to the effect of damping on page 300 of the paper, it is hardly likely that I should have overlooked the effect of variation of the damping. I do not think that I have anywhere stated in the paper that the galvanometer is a pivoted one ; as a matter of fact it is an ordinary suspended moving coil instrument. As this galvanometer is working on a constant external resistance there is no reason to anticipate any change in the damping.

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The next point that Professor Baily raises is as to the effect of the length of the pin. I am very sorry that, owing to a reorganisation of my laboratories this summer, hardly any experimental work could be done until a little while before the reading of the paper, and I have been consequently obliged to refer to these matters in the addendum, which will be printed with it. Professor Baily will see when this appears that I have taken into consideration all the points which he has brought up, and I have also suggested that the scale of the galvanometer could be empirically calibrated to allow for these effects. I must join issue, however, with Professor Baily as to the value of my experiment in turning down the outside of the cylinder in which the drilling was made. My fear had been that the exceedingly large area of the return path might have led to the reluctance of it being comparatively high owing to the iron of that return path being worked at a very low induction density, and I consider that this experiment conclusively proves that this effect does not exist. The area of the return-path was, as Professor Baily says, reduced to sixteen times the area of the pin, but this ratio is many times less than in any ordinary yoke permeameter. Professor Baily mentions that this reduction did not in the least affect the part just beyond the exposed part of the pin, but, as a matter of fact, when turning down the cylinder we also turned off one end so as to make the thickness of metal and the annular part at the bottom of the hole the same, and the effect appears to be very small. I do not, however, attach much importance to the bearing of this on the effect of the concentration of the lines.

I am obliged to Professor Baily for his reference to Professor Ewing's actual paper on the effect of the ends of the specimen, as although I knew the matter had been investigated by Professor Ewing, I had not ascertained the exact amount, and I am pleased to find that Professor Ewing's results confirm my expectation that the whole of the deviations between the results obtained by this method and by ordinary methods can be accounted for by the shortness of the pin. Professor Baily, however, appears to think that this error is inherent in the new method, but it is purely a matter of the proportions you choose to give to your pin. For commercial purposes, as I have before stated, I prefor to work to the dimensions given in the paper, and even possibly to use larger ones as suggested by Mr. Esson, while for laboratory testing there is no reason why the drilling should not be made 1 inch deep instead of $\frac{1}{2}$ inch and the pin reduced to $\frac{1}{10}$ inch diameter. This would give as great a ratio of length to the diameter as is used in the recognised yoke permeameters.

Professor Baily speaks of the error caused by the tooling on the small pin. I have already stated that I think this is quite negligible, and as a matter of fact, we have tried a specimen before and after annealing it, the results being almost identical. If the drill became blunt there is no doubt that difficulties might be caused, but as the drill is not a costly item and it could certainly take between fifty and a hundred cuts without re-sharpening, it should most certainly be discarded as soon as any blunting occurs.

Finally, Professor Baily states that he would hesitate to accept or

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reject a specimen of iron on the evidence of the permeameter. With due respect to him, I must point out that as far as this is concerned the instrument is absolutely perfect from the dynamo maker's point of view. If two specimens differ from one another by 2 or 3 per cent. in their permeability, the instrument will show it, whether the absolute values of the permeability are correct or not. It is perfectly easy for a dynamo maker to have by him a few specimens of iron which have been found to give satisfactory results, the drilling may be made, and the yokes of actual machines, and the indications of the instrument may be perfectly safely trusted as to whether any other specimen comes up to this standard or not. From the commercial point of view, as a rule, nothing more is necessary, and there can be no question that such tests would be of the utmost possible importance to all concerned in the employment of iron or steel for magnetic purposes. Of course I am anxious to have the apparatus correct from the scientific point of view as well, as its applications in research work are very numerous, but I see no difficulty whatsoever in obtaining this accuracy, and shall immediately proceed to secure it and to publish evidence on the point. I only regret that under the circumstances above mentioned it was impossible to do so before.

In conclusion I must cordially thank all those who took part in the discussion for the kind way in which they have received this contrivance, and the approval which they have expressed of it on the whole. I have been very glad to have the criticisms which have been brought forward, and am also glad to be able to say that every one of them are on points which we have already taken into consideration.

Although, as I have quite admitted, there are some criticisms to be made on the theoretical side to the instrument, I am perfectly satisfied with its commercial suitability, and I am also confident that, with a little more work, it can be made at least as accurate, if not much more so, than any permeameter hitherto devised.

The President.

The PRESIDENT: You have already accorded to Dr. Drysdale by your hearty applause your appreciation of his paper, for which we all thank him very much.

THE PHYSICAL PROPERTIES OF CERTAIN ALUMINIUM ALLOYS, AND SOME NOTES ON ALUMINIUM CONDUCTORS.

By ERNEST WILSON, Member.

By permission of the British Aluminium Company the author is able to make use of the results obtained from experiments made upon certain light aluminium alloys given to him to test. The experiments were made at King's College, London. The tensile properties and linear coefficients of expansion were found by Mr. H. M. Waynforth, A.M.Inst.C.E., in the Mechanical Engineering Laboratory, and the rest of the work was carried out in the Siemens Electrical Engineering Laboratory.

COMMERCIALLY PURE ALUMINIUM.

The purest aluminium obtained commercially contains traces of iron and silicon, giving about 99·6 per cent. of aluminium in the finished product. All aluminium may be said therefore to be used in the alloyed state. Table I. gives the result of tests made with aluminium wire, ·126 in. (3·2 mm.) diameter, containing ·31 per cent. Fe. and ·14 per cent. Si. It was tested in three states—(1) as received; (2) after being annealed in an oil bath at 100° C., and allowed to cool slowly in the oil; (3) after being annealed at 430° C. for two hours and allowed to cool in air. Experiment shows that in state (1) this wire returns to its original length after the application of any stress up to 16,000 lbs. per sq. in. The effect of prolonged loading upon tensile strength is still under investigation. The tensile properties at 15° C. are much altered after annealing at 430° C. Specific gravity and specific resistance at 15° C. are unaltered after annealing. The coefficient of expansion in each case increased slightly in value from 18° C. to 100° C., and after 100° C. increased more rapidly. Weight for weight the conductivity of this aluminium is double that of copper; or for a given length of conductor, carrying the same electric current with the same dissipation of energy, the relative weights are as 1 of copper to ½ of aluminium: the diameter of the aluminium wire being 1·27 that of the copper.

LIGHT ALUMINIUM ALLOYS.

Twenty-four alloys have been examined, and the results of the tensile tests are given in Table II. In Table III. the electrical properties are given as well as some of the tensile properties in order to facilitate comparison. It is important to indicate the order in which the experiments were made. Each sample was in the form of wire about 19 feet long and ·126 inch (3·2 mm.) diameter. The specific resistance of each wire was obtained in air first and again when placed in an oil bath at atmospheric temperature. The temperature coefficient was then determined, and the maximum temperature to which each sample was raised was about 100° C. When cold the specific resistance was again determined. Half of each wire was used for tensile tests and linear coefficient of expansion. The other half was partly used for density tests, for chemical analysis, and to investigate the effect upon specific resistance by annealing at 435° C. for half an hour and allowing to cool in air. The tensile tests refer to all specimens after being raised to 100° C.

In Table III. the specimens are arranged in groups of the principal impurities. The specific resistances first given are those obtained before the wires were heated, and give the resistance in legal ohms between the opposite faces of a cubic-centimeter at 15° C. The conductivity is expressed in terms of Matthiessen's standard taken at $1{\cdot}696 \times 10^{-6}$ legal ohms at 15° C. for copper.[1] Heating to 100° C. had the effect of increasing conductivity at 15° C. from 0 to about 1 per cent. in different specimens. Annealing at 435° C. increased conductivity at 15° C. as much as 4 per cent. in some specimens.

On plotting resistance in terms of temperature every alloy shows a small deviation from a straight line between atmospheric temperature and 100° C.: the curve is concave downwards when temperature is plotted horizontally.

The following remarks refer to what may be called the impurity, which is varied, although the silicon and iron, which are always present, are not constant in quantity.

Copper.—As soon as the proportion of copper (1·5 to 2 per cent.) is sufficient to give a breaking load of 40,000 and limit

[1] This result is taken because it is so much quoted. It is known to be as much as 2 per cent. too high for purer copper.

of elasticity of 33,000 lbs. per sq. inch, the specific resistance rises to 3·3 from $2·76 \times 10^{-6}$ ohms for pure commercial aluminium at 15° C. The temperature coefficient falls to ·0030 from ·0040, the linear coefficient of expansion is ·000024 as against ·0000234. Not much is gained in tensile strength by increasing copper from 1·5 to 2·5 per cent.

Zinc.—It cannot be said that the addition of zinc up to 2 per cent. improves the tensile properties of this alloy. In fact with 2 per cent. Zn. the breaking load has fallen below what it is with 1·2 per cent. Zn. For the same proportions the conductivity of the zinc alloy is greater than copper. The coefficient of expansion falls slightly with increase of zinc, whereas it rose with increase of copper.

Nickel.—This metal has a marked effect upon the breaking load, but the limits of elasticity remain low. For instance, 2·2 per cent. Ni. gives a breaking load of 38,600 and limit of elasticity 20,300 lbs. per sq. inch.

Nickel-Copper.—The alloy containing 1·29 per cent. Ni. and 1·08 per cent. Cu. gives a breaking load of 45,900 and limit of elasticity 36,600 lbs. per sq. inch—the highest of the series. This alloy is characterised by its comparative low percentage extension (·146 with 16,250 lbs. per sq. inch), its high coefficient of expansion (·0000252), and its low temperature coefficient (·00178). Its specific resistance is $3·41 \times 10^{-6}$ legal ohms at 15° C.

Nickel-Iron.—The alloy containing 2·6 per cent. Fe. and 1·39 per cent. Ni. gives 42,200 breaking load, and 24,400 limit of elasticity. Its specific resistance is 3·24 at 15° C., and its temperature coefficient (·0032) is nearly double that of the alloy last quoted. The coefficient of expansion (·0000222) is as small as any of the series.

Nickel-Zinc.—Five of these alloys have been tested. The greatest breaking load is 36,000, and the limit of elasticity remains low. The alloy containing ·83 per cent. Ni. and ·90 per cent. Zn. gives a comparatively low specific resistance, namely, $3·03 \times 10^{-6}$ ohms at 15° C.

Copper-Zinc.—Two of these alloys have been tested and they reveal nothing remarkable.

Iron-Manganese.—The alloy containing ·56 per cent. Fe. and 1·78 per cent. Mn. has a breaking load 35,300 and limit of elasticity 24,400 lbs. per sq. inch. The specific resistance is high.

Aërial Wires.

I have to thank Professor W. H. H. Hudson, M.A., for the following notes on the elastic catenary :—

Let $2a$ be the distance between the points of support.
" $2s$ be the unstretched length of the wire at a standard temperature.
" w be the weight of a unit length of the unstretched wire at the standard temperature.
" c be a length such that wc is the tension at the lowest point of the wire.
" l be a length such that wl is the modulus of elasticity of the wire, assumed to be independent of temperature.
" α be the linear coefficient of expansion of the wire per 1° C.
" t be the temperature in degrees C. below the standard temperature.

Then if αt be so small that its square may be neglected, it can be shown that the relation between the quantities is

$$\frac{s}{c} = \sinh\left\{\frac{a(1+\alpha t)}{c} - \frac{s}{l}\right\}.$$

A fall of $t°$ C. has therefore the same effect upon the tension as an increase of the distance between the points of support by an amount equal to $2a\alpha t$. The dip is

$$(1+\alpha t)\left\{\sqrt{s^2+c^2} + \frac{s^2}{2l} - c\right\}$$

From the above equation it follows that

$$\frac{a}{c} = \frac{s}{l} + \sinh^{-1}\left(\frac{c}{s}\right) \text{ at the standard temperature.}$$

$$= \frac{s}{l} + \frac{s}{c} - \frac{s^3}{6c^3} + \frac{3s^5}{40c^5} - \quad \text{"} \qquad \text{"}$$

Whence

$$a = \frac{cs}{l} + s - \frac{s^3}{6c^2} + \frac{3s^5}{40c^4} - \quad \text{"} \qquad \text{"}$$

For the purpose of comparison a length of each wire is supposed to be hung between two horizontal points of

support 120 feet apart, the unstretched length of the wire being equal to the distance between the points of support, and the temperature the standard temperature. Under these conditions the dip, in feet, and the tension at the lowest point of the wire have been calculated. The limit of elasticity of each wire has been found by experiment. Suppose the temperature falls in the case of each wire until the tension in that wire corresponds to the limit of elasticity (or, if preferred, any factor of safety can be taken, the same in each case), then a comparison of the temperature fall in the different cases is one basis of comparison with which to compare the wires as to their suitability as aërial conductors.

The increase in a, which would stress the wire to its elastic limits, has been found in each case, and the fall in temperature t calculated from the equation $2\,\delta a = 2a\,\alpha\,t$ where δa is the increase in a.

For the values of c, dealt with in this paper, $\frac{3\,s^5}{40\,c^4}$ and higher terms are negligible, and for values of c corresponding to the elastic limits the term $\frac{s^3}{6\,c^2}$ may also be neglected. At the standard temperature the dip is nearly 1 foot in each aluminium alloy and 1·3 foot in the copper specimen. The values of c at the standard temperature, and the values of c corresponding to the limits of elasticity, are given in Table III. This Table also gives the values of l and a in each case.

The fall in temperature in the last column of Table III. shows that the greater lightness of aluminium and greater percentage extension counteract the effect of greater linear coefficient of expansion. In the case of many of these alloys one may say that when erected as above described they are superior to copper for a given fall of temperature from a standard temperature.

The Board of Trade Regulations (Clause 17) for securing the safety of the public under the Electric Lighting Acts, 1882 and 1888, set forth that "Every support for an aërial line shall be of a durable material and properly stayed against forces due to wind pressure, change of direction of line, or unequal lengths of span. The factor of safety shall be for aërial lines and suspending wires at least 6, and for all other parts of the structure at least 12, taking the

maximum possible wind pressure at 50 lbs. per square foot. No addition need be made for a possible accumulation of snow." Consider a hard-drawn copper wire 0·4-inch diameter—the weight per foot length is 0·484 lbs. Assuming that the pressure on the wire due to wind is 0·6 of what it would be if the surface were flat, then at 50 lbs. per square foot the force per foot length is 1 lb. as against 0·484 due to gravity. The resultant of these two forces is 1·11 lbs., which is more than double the force of gravity. It is most important to consider the effect of wind, snow, ice, etc., and the swaying of the conductor.

It has been pointed out by Mr. Gavey[1] that a gale of wind produced eight or ten breaks in fifteen miles of overhead aluminium wire after a fortnight's erection. The wire had a diameter of ·124 inch, weighed 75 lbs. to the mile, its breaking load was 28,200 lbs. (12·57 tons) per square inch, it stood ten twists in 3 inches, its maximum resistance per mile was 6·158 ohms, and its specific resistance 2·974 ohms. With aluminium of the same total conductivity as copper, the wind-pressure will be about 1·27 times as great as in the copper. Since the cross-sectional area of a wire varies as the radius squared, and the area exposed to wind-pressure, snow, etc., varies as the radius, it follows that for a given material the larger the diameter the better. In other words, two separately strung wires of equal diameter are not so good as one wire of $\sqrt{2}$ the diameter of either of the other two, although the total conductivities are the same in the two cases. Comparing aluminium with copper, the total tensile strength of an aluminium wire of the same total conductivity as the copper may be greater according to the alloy chosen, and this may compensate for the increase in the surface exposed to wind. The breaks in the above telegraph line occurred at different parts of the wire—not at the insulators or joints. As pointed out by Mr. Gavey, the failure may be due to want of uniformity in manufacture, which is now improved. Further information would be required before one could calculate if 12·57 tons per square inch would be exceeded in a gale of given velocity. The small diameter may have something to do with the breaks which occurred. It is significant that in the long power transmissions, stranded

[1] See *Journal Inst. Elec. Eng.*, 1901, vol. xxx., p. 359.

conductors of aluminium having in some cases 0·75-inch external diameter are used, and apparently they do not break. If a cheap method of insulating aluminium wires could be found so that a stranded cable of insulated telegraph or telephone wires could be erected instead of a number of separate wires, the effects due to wind-pressure might be reduced. The saving in insulators might, to some extent, compensate for increased cost of insulation. The Standard Electric Company of California[1] in their 43-mile transmission employ aluminium wire 0·294-inch diameter. The resistance per mile at 25° C. is stated to be 1·00773 ohms (this would give a specific resistance of $2·878 \times 10^{-6}$ ohms at 25° C.). The conductivity is stated to be 59·9 per cent. as compared with copper. The breaking load is 22,800 lbs. (10·1 tons) per square inch. With a stress of 14,500 to 17,000 lbs. per square inch, a marked increase in permanent elongation took place. The wire took a permanent set almost from the commencement of application of load. It seems, therefore, with a diameter of 0·294-inch, aluminium wires having a lower breaking load than the aluminium in Table I. are employed. In the new line an aluminium stranded cable ¾-inch diameter is to be used.

The Niagara Falls Power Company in their new line to Buffalo employ three cables each of 37 strands. The span between the poles, which in the copper line is 75 feet, averages 112½ feet in the aluminium line. Besides this there is the saving in transport, since for the same conductivity only half the weight of aluminium is required.

For single small-sized wires, where great tensile strength is required, Cu. and Ni.-Cu. alloys (see Table III.) might be tried and further investigated with advantage, but a sacrifice must be made on the part of conductivity. For large single or stranded conductors the pure commercial aluminium (Table I.) should be found sufficiently strong, and its conductivity is a maximum.

The subject of corrosion is one of great importance, especially in districts where the air is vitiated by chlorine, etc. I have specimens of conductors which have been exposed to atmospheric conditions and used at the same time to transmit electric current. One of them has been in use for four years at Foyers, and it cannot be said that it

[1] See Perrine and Baum, *Electricity* New York), May 30, 1900.

has seriously suffered from corrosion. Mr. Kershaw[1] has exhibited samples of conductors which have been exposed to atmosphere at St. Helens, where there are chemical works. In such districts a solid conductor would expose a smaller surface to the air than if stranded, and might prove preferable.

Since aluminium is electro-positive to other metals, it is important only to use this metal in making joints. So far as I am aware, all joints on overhead aluminium lines have been free from welding or soldering, except perhaps the telegraph joint, in which the two ends are brought together (after making the joint in the ordinary way) and soldered or welded. The construction of mechanical joints, as also the art of welding and soldering aluminium, are now known.

The net price of aluminium is now less than £130 per ton. Copper stood at £73 (less 2½ per cent.) per ton on November 5, 1901. For equivalent conductivity the price is slightly in favour of aluminium. If the world's output of aluminium were doubled it would only be about 2 per cent. of the world's output of copper,[2] so that a considerable reduction in the price of aluminium might be effected without disturbing the price of copper.

A great deal of time has been spent upon these tests, and I wish to thank Mr. F. S. Robertson and Mr. W. Marden for their patience and care. Mr. L. G. Nunes carried out the density tests, for which I have to thank him.

[1] See *Journal Inst. Elec. Eng.*, 1901, vol. xxx., p. 348.
[2] See *Engineering*, vol. lxxii., p. 436.

TABLE I.

Number of Wire.		Specific Resistance in 10−6 legal ohms at 15° C.	Conductivity in terms of Matthiessen's Standard at 15° C.	Temperature Coefficient 0° C. → 100° C.	Linear Coefficient of Expansion per 1° C. between 18 and 100° C.	Specific Gravity.	Limit.		Break.		E.		Percentage Elongation on 350 mm., including break.	Percentage Reduction of area at break.	Remarks.
							Load in lbs.	Tons per sq. in.	Load in lbs.	Tons per sq. in.	Lbs. per sq. in.	Tons per sq. in.			
(1)	1						260	8·71	353	12·64					All three specimens broke well within the marked length, and the break in each case was a good cup-shaped fracture.
	2						240	8·60	350	12·53	8,512,000	3,800	1·86	73·6	
	3						250	8·65	353	12·64					
Averages for (1)		2·762	61·5	·00405	·0000234	2·715	250	8·65		12·60	8,512,000	3,800	1·86	73·6	
(2)	1						260	8·71	341	12·21			1·34		Specimen 1 broke outside marked length, near bottom grip; the others went well with similar fracture to (1).
	2						250	8·65	342	12·24	8,512,000	3,800	2·32	76·7	
	3						240	8·60	342	12·24					
Averages for (2)		2·762	61·5	·00405	·0000231	2·715	250	8·65	342	12·24	8 512,000	3,800	2·32	76·7	
(3)	1						95	3·4	180	6·44			24·3	89·5	All three specimens broke well within the marked length, and showed good fractures. 1 was broken very slowly. 2 was broken fairly quickly after limit was reached. 3 was broken quicker than 1, but more slowly than 2.
	2						95	3·4	180	6·44	1,683,240	751	20·9	85·6	
	3						95	3·4	180	6·44			22·3	89·5	
Averages for (3)		2·762	61·5	·00393	·0000230	2·715	95	3·4	180	6·44	1,683,240	751	22·5	88 2	

TABLE II.

No. of Wire.	Limit.		Breaking.		E.		Per cent. Elongation on 350 m.m., including Break.	Per cent. Reduction of Area at Break.	Ratio Limit ÷ Breaking load per cent.	Remarks.
	Load in lbs.	Tons per sq. inch.	Load in lbs.	Tons per in.²	Tons per sq. in.	Lbs. per sq. in.				
1	290	10·38	346	12·39	2,500	5,600,000	1·69	62·4	83·8	*a.* Distinct flaw from side to centre; traceable along length of wire. *b.* As *a*, but flaw less marked; broke outside marked length.
2	250	8·95	375	13·42	4,160	9,320,000	1·40 1·94	76·3	66·7	*a.* Good homogeneous cup fracture; broke outside marked length. *b.* Do. do. do. *c.* Signs of a longitudinal split. *d.* Do. do. and surface cracks; broke well between marks.
3	275	9·85	375	13·42	3,980	8,916,000	3·15	78·5	73·3	*a.* Good break; fine homogeneous cup-shaped fracture; very slight signs of longitudinal cracks. *b.* Do. do. do. do.
4	220	7·88	316	11·31	3,670	8,220,000	3·44	76·6	69·0	*a.* Broke quite slowly; section homogeneous; curious split on each side of break, as though metal had wrapped over during drawing. *b.* Signs of some sort of cracks, but not so marked as *a*; very good break and section.
5	255	9·13	320	11·46	4,180	9,362,000	2·44 3·20	76·6	79·7	*a.* Break outside marked length; good fracture. *b.* Do. do. do. *c.* Good break; for *a*. *b*. and *c*. the fracture is slightly coarse.
6	300	10·74	380	13·60	3,020	6,764,000	3·43	81·7	78·9	*a.* Good break; homogeneous material; finer than 5. *b.* Do. do. do. Also slight signs of longitudinal splitting.
7	250	8·95	365	13·07	3,790	8,490,000	1·72 2·94	57·2	68·5	*a.* Broke outside marked length, radial flaw extending from outside to centre. *b.* Good break; similar flaw showing, but not so marked as in *a*.
8	290	10·38	415	14·86	3,020	6,764,000	2·54 4·05	46·4	69·9	*a.* Broke in top grip; good cup-shaped section. *b.* Good break; rather curious fracture; slight signs of longitudinal splitting.
9	275	9·85	375	13·42	3,920	8,780,000	1·48 2·05	68·3	73·3	*a.* Good break; homogeneous; one side of break has a small sharp projection and the other a corresponding depression. *b.* Broke outside marked length. *c.* Good break, cup-shaped homogeneous fracture.
10	280	10·02	360	12·89	3,740	8,376,000	2·43	70·1	77·8	*a.* Good cup-shaped homogeneous fracture. *b.* Do. do. do. *c.* Do. do. do. *d.* Do. do. do.
11	300	10·74	425	15·23	3,690	8,266,000	3·13 3·84	52·4	70·6	*a.* Good homogeneous fracture. *b.* Do. do. Broke outside marked length.

12	265	9·49	390	13·96	3,640	8,154,000	*2·16* 2·90	55·7	67·9	*a.* Broke outside marked length; good homogeneous cup fracture. *b.* Fracture at about 45°; signs of fracture having commenced about 2 m.m. below actual break; flakey marks all along one side of specimen. *c.* Similar to *b*, but not so marked.
13	400	14·32	480	17·19	3,690	8,266,000	3·71	59·8	83·3	*a.* Good break; very curious cross at centre of break; the cross is female on *each* side; slight flakey appearance down one side (of surface). *b.* Same as *a*, but no flakey appearance.
14	400	14·32	500	17·90	3,920	8,780,000	*3·43* 4·19	66·8	80·0	*a.* Homogeneous cup-shaped fracture. *b.* Ditto, broke outside marked length. *c.* As *a*.
15	425	15·22	535	19·15	3,860	8,646,000	*1·88* 3·08	60·7	79·4	*a.* Fine homogeneous cup-shaped fracture; broke outside marked length. *b.* Ditto, but broke well between marks. *c.* As *a*.
16	240	8·59	328	11·74	4,050	9,072,000	*2·54* 3·08	83·0	73·2	*a.* Good cup break; drew down very much locally; broke outside marked length. *b.* Ditto, broke *in* marked length. *c.* As *a*.
17	225	8·06	390	13·96	3,740	8,376,000	*1·51* 2·32	60·6	57·7	*a.* Good cup-shaped homogeneous fracture. *b.* Ditto; broke outside marked length; a few very small flaws visible under glass.
18	275	9·85	425	15·22	3,790	8,490,000	*0·77* 2·09	49·0	64·7	*a.* Broke outside marked length; ragged break not much drawn down. *b.* Good cup-break, homogeneous material.
19	250	8·95	445	15·93	4,490	10,060,000	2·96	25·4	50·2	*a.* Good homogeneous cup fracture. *b.* Ditto, more marked than *a*.
20	250	8·95	475	17·01	3,800	8,520,000	*3·33* 4·40	42·9	52·6	*a.* Good fracture; no flaws; not much drawing down. *b.* Ditto; broke outside marked length. *c.* Good homogeneous cup fracture.
21	300	10·74	520	18·62	3,690	8,266,000	2·62	38·4	57·7	*a.* Good homogeneous fracture; not much drawing down. *b.* Do. do. do.
22	450	16·11	565	20·23	4,910	11,000,000	0·57 testing at ordinary rates. 1·83 testing very slowly and carefully.	19·3	79·7	*a.* Very sudden break and very little drawing down; very perfect male and female cone. *b.* Ditto, but not so perfect as *a*. *c.* Load put on very slowly and carefully; cup break and draw down more than *a* or *b*.
23	300	10·74	435	15·57	3,860	8,646,000	2·03 2·25	49·1	69·0	*a.* Good homogeneous fracture; irregular cup. *b.* Broke outside marked length; fracture as *a*. *c.* As *a*.
24	250	8·95	385	13·78	3,690	8,266,000	3·83	60·8	64·9	*a.* Distinct flaw at one side of fracture caused by presence of a globule of foreign matter. This result is neglected in averages. *b.* Good homogeneous fracture; no flaws. *c.* Do. do.

Note.—Per cent. elongations printed in italics did not include break.

TABLE III.

Number of Specimen.	Analysis. Si	Fe.	Cu.	Ni.	Mn	Zn.	Al	Specific Resistance in 10^{-6} legal ohms at 15° C.	Conductivity per cent. in terms of Matthiessen's Standard taken to be 1600×10^{-6} legal ohms at 15° C. for Copper.	Average Temperature Coefficient per 1° C. between 0° C. and 50° C.	Average Temperature Coefficient per 1° C. between 0° C. and 100° C.	Specific Resistance at 15° C. after Annealing for ½ hour at 435° C. and Cooling in Air.	Percentage extension with 16,250 lbs. per square inch of cross-section.	Limit of Elasticity in lbs. per square inch cross-section.	Breaking Load in lbs. per square inch cross-section.	Average Linear Coefficient of expansion per 1° C. between 16° C. and 100° C.	Specific Gravity before Annealing at 435° C.	Data for Elastic Catenary. l in 10^6 feet.	c when hung at the Standard Temperature in feet.	c corresponding to Elastic Limit in ft.	Fall in Temperature required to stress to Elastic Limit in degrees C.
16	31	·37	·11	...	...	...	99·21	2·92	58	·00354	·00318	2·83	·177	10,500	26,600	·0000236	2·719	7·7127	1666·4	16,240	89·5
4	38	·25	·16	...	...	...	99·21	2·88	58·9	·00341	·00324	...	·200	17,000	25,700	·0000234	2·748	6·7885	1597·0	14,917	93·9
13	38	·25	1·58	...	...	...	97·79	3·34	50·7	·00295	·00283	3·30	·194	32,500	39,000	·0000239	2·748	6·9508	1609·6	27,080	163·0
14	40	·31	1·80	...	..	...	97·43	3·25	52·1	·00302	·00303	3·18	·183	32,500	40,660	·0000240	2·748	7·3857	1642·5	27,080	152·7
15	40	·40	2·61	...	...	...	96·59	3·34	50·7	·00311	·00296	3·26	·180	34,500	43,500	·0000241	2·764	7·2309	1631·0	28,750	165·0
1	38	·22	·17	...	...	·62	98·61	2·80	59·2	·00309	·00357	...	·286	23,600	28,100	·0000245	2·720	4·7574	1418·5	19,667	169·0
2	43	·28	·30	...	...	1·20	97·79	2·94	57·0	·00346	·00320	...	·171	20,300	30,500	·0000241	2·728	7·8045	1679·4	16,916	88·5
5	43	·30	·18	...	...	2·04	97·05	3·07	55·2	·00319	·00325	...	·171	20,700	26,000	·0000230	2·749	7·8724	1677·8	17,250	95·3
7	37	·25	·05	·75	...	...	98·58	3·05	55·6	·00328	·00320	...	·180	20,300	29,700	·0000246	2·723	7·2047	1629·0	16,917	95·5
8	35	·21	·06	1·00	...	...	98·38	3·24	52·3	·00337	·00320	...	·237	23,600	33700	·0000239	2·731	5·7253	1508·8	19,667	145·5
20	37	1·10	·06	2·25	...	...	96·22	3·18	53·2	·00335	·00320	3·14	·180	20,300	3 8600	·0000234	2·756	7·1462	1624·6	16,917	101·2
24	35	1·16	·09	...	...	...	98·40	2·97	57·1	·00365	·00357	2·955	·194	20,300	31,300	·0000248	2·731	6·994	1613·0	16,917	97·6
3	37	·28	·68	...	...	·50	98·17	3·06	55·3	·00327	·00300	...	·180	22,300	30,500	·0000227	2·732	7·544	1654·2	18,583	108·5
6	39	·31	·63	...	...	1·20	97·47	3·12	54·3	·00324	·00316	...	·237	24,400	30,000	·0000244	2·742	5·7023	1506·8	20,333	146·1
17	35	·53	·10	·83	...	·90	97·27	3·03	56	·00324	·00320	3·005	·191	18,300	31,700	·0000239	2·751	7·0382	1616·4	15,250	91·9
12	31	·59	·10	1·00	...	·73	97·09	3·33	50·9	·00330	·00318	3·18	·197	21,500	31,700	·0000236	2·738	6·8817	1604·3	17,000	110·2
18	43	·40	·21	1·13	...	1·04	95·80	3·24	52·4	·00332	·00310	3·245	·180	22,300	34,500	·0000245	2·703	7·1004	1621·1	18,583	106·8
19	35	·29	·11	2·01	...	1·77	95·47	3·26	52	·00263	·00238	3·205	·160	20,300	36,200	·0000225	2·770	8·3952	1714·2	16,917	89·6
11	30	·59	·24	2·31	...	·38	96·12	3·48	48·7	·00308	·00300	...	·194	24,400	34,500	·0000235	2·741	6·9686	1611·0	20,333	124·1
22	37	·43	1·08	1·29	...	...	96·83	3·41	49·7	·00173	·00178	3·28	·146	36,600	45,900	·0000252	2·747	9·2532	1770·7	30,500	131
21	39	2·57	·10	1·39	...	...	95·55	3·24	52·3	·00352	·00320	3·105	·194	24,400	42,200	·0000222	2·770	6·8956	1605·4	20,333	132·8
10	32	·54	·02	...	·05	...	99·07	3·09	54·8	·00322	·00311	...	·191	22,700	29,200	·0000222	2·722	7·1132	1622·1	18,917	119·7
9	31	·35	·03	...	·35	...	98·96	3·30	51·3	·00311	·00291	...	·183	22,300	30,500	·0000231	2·733	7·4235	1645·3	18,583	108·4
23	44	·56	·09	...	1·78	...	97·13	3·40	48·6	·00273	·00245	3·35	·180	24,400	35,300	·0000230	2·750	7·2077	1633·7	20,333	121·6
Pure	14	·31	Commercial Aluminium ...					2·762	61·5	...	·00393	...	·190	19,376	28,200	·0000234	2·715	7·2473	1632	16,497	97·5
	Hard-drawn Copper							...	98	...	·00388	...	·102	27,850	64,000	·0000170	8·914	4·1314	1353	7,222	102

ADDENDUM.[1]

(Read at the Meeting on December 12th, 1901.)

At the close of the last meeting Mr. Gavey gave me some particulars with regard to the aluminium wires to which I referred in my paper. I have made a few calculations therefrom, the results of which are given in Table IV. Mr. Gavey told me that the distance between the horizontal points of support was 180 feet, that the wind-pressure might have varied from 14 lbs. to 20 lbs. to the square foot, and that the wire was stressed at the insulators when erecting to the extent of 35 lbs. on the total section. The wires broke when this wind came, without any fall in temperature, and without any accumulation of snow, ice, etc. The figures in Table IV. also relate to a copper wire which is supposed to be hung between horizontal points of support 180 feet apart. The copper wire has the same unstretched length and electrical resistance as the aluminium wire. The wind is assumed to have a horizontal pressure of 20 lbs. to the square foot at right angles to the straight line passing through the points of support. In the case of the aluminium the total stress at the insulators was 35 lbs., without any wind blowing; the copper wire will have a corresponding total stress of 51 lbs. When the wind is blowing the total stress on the aluminium wire comes out at 135 lbs. and on the copper wire 126 lbs. Expressing these in lbs. per square inch of the cross-sectional area of the wires we have 11,560 with the alu-

TABLE IV.

Metal.	Diameter in inches.	Cross-sectional area in sq. inches.	Wind pressure per foot length in lbs.	Weight per foot length in lbs.	Resultant in lbs.	Limit of Elasticity in lbs. per sq. inch.	Breaking load in lbs. per sq. inch.	Stress in lbs. Without wind. Total.	Stress in lbs. Without wind. Per sq. inch.	Stress in lbs. With wind. Total.	Stress in lbs. With wind. Per sq. inch.	Sag in feet. Without wind.	Sag in feet. With wind.
Commercially pure aluminium ...	·124	·01207	·1378	·0142	·1385	19,376	28,200	35	2,898	135	11,560	1·9	4·1
Hard-drawn copper	·0977	·007497	·1086	·0289	·1124	27,850	64,000	51	6,850	126	16,900	2·2	3·54

[1] [This Addendum was read at the Ordinary General Meeting of December 12th, but in order to facilitate reference it is printed here, together with the other portion of the proceedings at that meeting having relation to Professor Wilson's paper.—*Ed.*]

minium, and 16,900 with the copper wire. The sag in feet of these wires under the two conditions has been calculated. The theory of the elastic catenary would tell us that without the wind the sag in feet is 1·9 for the aluminium and 2·2 for the copper. With the wind the sag increases to 4·1 in the aluminium and to 3·54 in the copper. The factor of safety as between the limits of elasticity and the actual stress in these wires when in the wind is about the same in the two cases, namely, 1·7 and 1·6. Looking at it from this point of view it is difficult to argue that the aluminium wire should break in preference to the copper one. If you take it on the breaking load there is a larger factor of safety in the case of the copper, because the breaking load is 64,000, as against 28,000 in the case of the aluminium. It seems to me that probably Mr. Gavey is right, and that the breakages may be due to want of uniformity in manufacture. I may add that since the time that these Post Office experiments were made uniformity in the manufacture of the metal has improved. Recently erected aluminium wires at Larne, which is in a very exposed position, have withstood a recent severe storm, and have not broken. These figures are the result of theory, and my regret is that I cannot confirm them by the results of actual experiment. If you watch a wire swinging in the wind, it will swing to a considerable amplitude, and then it will come to rest; if a gust of wind comes on to the wire at the right moment, I believe it can be stressed much more severely. Every time the wire swings to and fro it experiences varying stresses because it is expanding and contracting, if it is stressed within the limits of elasticity. That brings in the subject of the fatigue of the materials. The wire which was used in the Post Office experiments was constructed of pure commercial aluminium. The most successful alloys which are mentioned in the paper are those of copper in one instance and nickel-copper in the other. The addition of 1·29 per cent. of nickel and 1·08 per cent. of copper had the effect of raising the limit of elasticity from 19,000 lbs. to 37,000 lbs., whereas for copper it is 28,000 lbs. So that the small addition of the nickel and copper greatly improves the tensile strength of the wire; in fact it raises the breaking load from 28,000 lbs. to 46,000 lbs. per square inch. I have samples of the twenty-four alloys which are mentioned in this paper suspended on the roof of King's College, London, in order to see what the effect of the London atmosphere will be on them. If these alloys are satisfactory in regard to uniformity in manufacture and corrosion there is no reason why they should not be successfully used for the purpose of overhead telegraph or telephone wires. Those are the chief points I wish to mention, and with your permission I will add them to the paper.

Mr. Gavey. Mr. J. Gavey (*communicated*): In the discussion on Mr. Kershaw's paper on "The Use of Aluminium as an Electrical Conductor" in January last, I mentioned the fact that the Post Office had erected about fifteen miles of aluminium wire in the Potteries district with a view to test its suitability for telegraph or telephone lines, and that the result of the experiment was not very satisfactory, a gale of wind having broken the wire in eight or ten places within a fortnight after its erection, whilst copper wires erected in the same locality were unbroken.

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This occurred on two or three occasions, and the aluminium wire was ultimately taken down. The breaking load of the aluminium wire when tested in the usual manner varied between 340 lbs. and 363 lbs., and its diameter between 124 and 125½ mils. (not 1·24 millimetres as rendered in the report of my remarks in January). After erection the stress at the insulators was only 35 lbs. at 45° Fahr. in a 60-yard span, the corresponding dip being 1·64 feet. There was therefore an apparent factor of safety of about 10½ at that temperature, and in the absence of snow the cause of the breakdown was not quite obvious. When finally removed, by which time the wire had become to a certain extent corroded, samples selected at random still showed a tensile strength of 325 lbs. when the breaking load was applied in the ordinary way by means of a lever machine. It occurred to me that this method of ascertaining the tensile strength had probably not fully revealed the

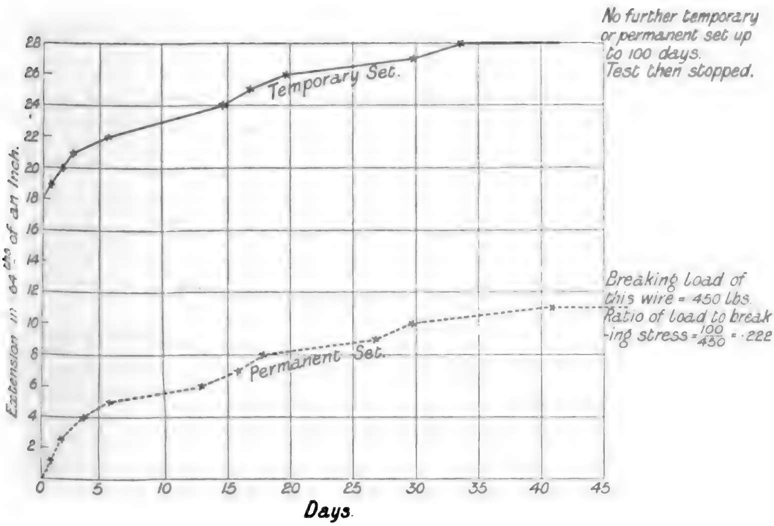

FIG. A.—Aluminium Bronze.

facts, and I had certain samples, 36 feet in length, suspended vertically and permanently weighted. These further tests showed that one of the chief causes of the failure was an exaggeration of the well-known phenomenon of "fatigue" in the metal, and that this defect was more strongly marked in the wire that had been erected than in new wire. It will be seen from the annexed table that in the case of samples that had been erected a load of only about one-eighth of the apparent breaking load was sufficient to produce a permanent elongation, and that a load of two-thirds of the nominal breaking stress caused actual rupture when continuously applied for about three weeks.

The elongation depends largely upon the length of time the load is applied if it exceeds a certain value (about 2,900 lbs. per square inch in the case of "pure" aluminium), and proceeds at a gradually increasing rate

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for about a fortnight ; the temporary or elastic deformation which at first occurs with light loads being transformed into permanent elongation or set. There is in such cases a slight recovery after a period of rest, but it is inconsiderable. New aluminium wire gave better results, but showed the same characteristic defects. Certain specimens of aluminium bronze wire (composition unknown) had a tensile strength about 20 per cent. greater than that of pure aluminium, and compared favourably with it in respect of ductility, toughness, and elasticity ; whilst the electrical conductivity was only about 6 per cent. less. The behaviour of this wire under a load of 100 lbs., or 0·222 of the ordinary breaking stress, is shown by the curves in Fig. A. The wire was permanently elongated when loaded with a weight of 40 lbs., if the loading were continued for several days ; but no appreciable set occurred if the weight were removed after an hour or so.

Hard Copper Wire.—It is well known that a permanent set is also produced in hard copper wire by comparatively light loads, if the

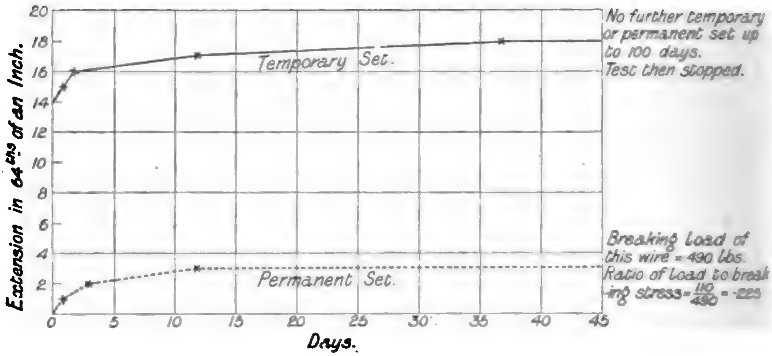

FIG. B.- Hard Copper.

stress be maintained sufficiently long. For instance, a wire 0·097 inch in diameter, and having a breaking stress of 490 lbs., if loaded with 110 lbs., recovers its original length on removal of the load, provided the loading has not been continued too long. If, however, the load be kept on for, say, 24 hours, a permanent elongation of $\frac{1}{64}$ inch is produced in a length of about 40 feet. This permanent elongation is a function of the time with a given load, increasing to about $\frac{1}{32}$ inch in three days, and to about $\frac{3}{64}$ inch in a fortnight (*vide* Fig. B). After this time no appreciable increase of permanent elongation occurs.

The true elastic limit of hard-drawn aluminium or copper wire is difficult to determine, owing to the effects of fatigue referred to above. In the cases of the suspended conductors, dealt with in these experiments, we should take the limit to be at that point at which no permanent elongation occurs, when the load is applied for an indefinite

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MECHANICAL TESTS OF SPECIMENS OF ALUMINIUM WIRE.

Specimen No.	Description.	Length. Feet.	Weight per Mile. lbs.	Breaking stress under ordinary conditions. lbs.	Load on Wire. lbs.	Time during which wire loaded. Hours.	Elongation per cent.	Remarks.
1	Aluminium recover'd from Potteries	36	75	325	—	—	—	Samples 1 to 7 corroded by exposure to air in Potteries district.
2	"	36	75		300	½	0·52	Wire suspended vertically; broke after half-hour under given load (300 lbs.)
3	"	36	75		280	5	1·07	Ditto; broke after 5 hours.
4	"	36	75		240	118	0·93	Ditto; broke after 118 hours.
5	"	36	75		220	525	2·54 (Elongation after time named.)	Ditto; broke after 525 hours.
6	"	36	75		150	1,900	0·23	Not broken; still stretching, but at decreasing rate.
7	"	36	75		100	3,500	0·12	Ditto. Ditto.
8	Aluminium from stock not erected	36	75		200	3,600	0·81	Ditto. Ditto.
9	"	36	75		150	2,600	0·23	Ditto. Ditto.
10	"	36	75		120	2,600	0·17	Ditto. Ditto.

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time. On this basis the elastic limits of these specimens are approximately as follows :—

Pure Aluminium ...	...	2,900 lbs. per square inch.
Aluminium Bronze	...	3,200 ditto.
Hard Copper ...	...	8,000 ditto.

To revert to the causes of the breakdown in the Potteries district, it is obvious that in addition to the susceptibility to fatigue of the aluminium wire, the wind pressure in the case of so light a metal will be a predominant factor in the total stress during a gale, and therefore the increased diameter necessary to maintain conductivity becomes of considerable importance. If, for example, we assume that the wind pressure on the round wire is two-thirds of that on a flat strip equal in width to the diameter, the stress on the wire at the insulators if it were inextensible would be increased from 35 lbs. to $35\sqrt{1+\left(\frac{0972}{0142}\right)} = 242$lbs., 0·0972 being the wind pressure in lbs. per foot run of wire, equivalent to 14 lbs. on the square foot, and 0·0142 the weight of the wire per foot. The elongation of the wire under this pressure, due to elasticity or to mere extension by increasing the sag, of course diminishes this stress materially, so that if we assume that in this case an elongation of 0·5 per cent. were possible without rupture, this stress would be reduced to 50·8 lbs. at the insulator. Apparently nothing like this percentage of elongation could be reached in the brief periods of pressure due to the sudden gusts, and the wire was no doubt broken through wind pressure alone.

Professor Wilson.

Professor E. WILSON (*communicated 13th January*, 1902): I wish to thank Mr. Gavey for the interesting results of his experiments, a copy of which I received on the 11th instant. He deals with a most important question. Believing that continued loading might have an important bearing upon the suitability of these alloys as aërial conductors, I started, as stated in the paper, a series of experiments, which Mr. Waynforth is at present engaged upon. We hope to publish the results of these experiments.

The President.

The PRESIDENT: If there is no further discussion upon the paper—I anticipated that scarcely anything would be said, it being a subject which is more interesting from a study of the figures of the very elaborate data which Professor Wilson has been good enough to produce—I will ask you to pass a hearty vote of thanks to Professor Wilson for his very instructive paper.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members:

Charles Leven.	George Russell.
R. B. Owens, M.A., M.Sc.	Reginald Russell Sinckler.

Wilfred Cyril Thomson.

Associate Members:

Francis G. Bell.
William Cramp.
George Herbert Sands Drewett.
James Fiddes-Brown.
Frederick Fisher.
John Hambly.
Harold Thornthwaite Hincks.
Archibald William Johnston.
Arnold Waldemar Mindo.
Walter Henderson Molesworth.
Arthur M. Simpson.
James Sugden.
Ernest John Summerhill.
Frederick Emil Ussing.
Robert Alex. Widdicombe.
John Gordon Wilson.

Associates:

Walter Ainscough.
Edward Boyes Austin.
Sydney Horace Barber.
Henry Louis Battersby.
Sidney Blandford.
Robert Foster Collinge.
Harry John Ede.
John William Fielding.
John William Gibson.
Gerald Higginbotham.
Vernon Hope.
Robert Salmon Hutton.
Herbert Jackson.
Frank Kieffer.
Arthur John Macphail.
Walter Edward Middleton.
Ernest Arthur Reynolds.
John Albert Robinson.
Henry Rodolph de Salis.
David B. Selkirk.
Wladimir S. Smeeliansky.
J. P. Smith (Councillor).
Harry Francis Jackson Thompson.
Frederick Ernest Trill.
Charles J. Turner.
Herbert George White.
Ferrand Agnew Williams.

Students:

William Melland Booth.
Lionel Calisch.
John Basil Edwards.
Llewelyn Thos. Edwards.
Selborne Evans.
Leonard Edmund Selmes Jackson.
Rudolph John Kaula.
Charles Balbarrie Kinnes.
Halsall Owen.
Henry Sayle Poole.
James Henry Soames.
Charles Ernest Wigg.

NEWCASTLE LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

Delivered November 18, 1901.

By John F. C. Snell, Member.

The number of addresses which are given from the chair in these days makes it a matter of some considerable ingenuity on the part of one to whom such a responsibility may fall to select a subject worthy of the Institution, or section of an Institution, over which he for the time presides.

I should like to draw attention to some of those useful objects which are being sought by the Institution of Electrical Engineers, and in furtherance of which our Local Sections may be useful, and, like the tributaries of some great river, help to feed into and assist in supplying energy to the Parent Institution. I should like also to say a few words to the students of the Local Section, and to address you on a subject which can be based on my own limited experience in engineering, and more particularly on that special branch of this comprehensive industry to which we happen to belong.

This recent development of a series of Local Sections to me seems a most statesmanlike move on the part of the Council. Members of all classes who are unable to benefit by attendance at the London meetings can meet together at Colonial and Provincial centres, not only to discuss papers prepared by the members of their own Section, but also to continue the discussion locally on papers of special interest which may be read in London. I am convinced that this must conduce to the welfare of the Institution, and of the whole electrical profession. The promotion of Colonial centres must act, moreover, as a further link in the Imperial chain, knitting our Colonial brethren more closely to the Mother Institution, and to the Mother Country. I trust that these Local Sections will promote an *esprit de corps* among members of all classes, and particularly among students. In time the Sections will take up such subjects as were suggested during the last Session of our own Section, studying those matters locally, condensing information concerning them, and assisting the Headquarters Council in many important problems, such as Standardisation, Electrical Wiring, and the Legislation affecting the electrical industry.

The applications of electricity are becoming more universal every year, and must become eventually as universal as are those of steam and gas to-day. It follows from the great natural law of the survival of the fittest that electricity so easily and efficiently transformed at will into either light, heat, or mechanical power, with machines in which there is so little loss of energy, must displace other less efficient agents. It is simply a question of time, but it will inevitably come, just as all other known things in this Universe evolve from a less to a more efficient condition.

As each individual member is a unit in the great machine, and as the efficiency of the whole depends upon that of the parts, each one of us must make himself as proficient as his opportunities will permit, not only to become a useful and self-helping citizen, but also in order to assist in that wider duty, viz., the ever-increasing, more efficient application of a natural force, the mysteries of which we are gradually but surely unravelling. This increase in efficiency will result in a more thrifty use of those stores of energy which nature has given us, and also in the less selfish application of them for our present use, having regard to those who must come after us. If we do not recognise this duty the Nemesis of ignorance will surely follow.

"If the gatherer gathers too much, Nature takes out of the man what she puts into his chest, swells the estate, but kills the owner."

It is my belief that it would react happily on the present, and we should individually benefit from this improved and more thrifty application of natural riches. But as any organic structure is dependent upon the cells of which it is built up, so if our whole scientific organisation is to become imbued with these principles, each individual member must act upon them, and not allow the canker of selfishness to impair his own efficiency. I particularly address myself to my contemporaries and to students who, imbued with these ideas, will not only faithfully undertake each duty given to them, but will endeavour to make the highest use of their abilities in those departments to which they have been called.

Any engineer must be proud to assist, however slightly, in—to quote from the Charter of the Institution of Civil Engineers—the "application of the great sources of power in Nature to the use and convenience of man." There is nothing like enthusiasm for one's work to enable one to overcome the obstacles with which one meets, acquire perseverance, develop character, and achieve success.

I am often asked by people who wish to know how their sons can become electrical engineers, and by students already entered upon their professional career, how they can specialise for one of the many branches which are open to them. In addition to advising the scientific subjects which they should master, it is important to remember that at the root of all lies the fundamental necessity of real work, not only to make money, but much more to assist—be it ever so slightly—in the development of applied science for the advancement and improvement of our fellow-creatures.

I will now pass on to that branch of electrical engineering in which I have been engaged, viz., the distribution of energy from central generating stations. It is but a few years ago that the lighting of the Thames Embankment was effected from a small station by generators of a type which would now be considered almost antediluvian. This was then looked upon as a wonderful experiment. Everything novel is at first considered marvellous. In a few years, as to-day with electrical matters, even children take them as a matter of course, and discuss them not unlearnedly. Now, only some eighteen years later, no less than eighty-one municipalities have installed their own electrical undertakings, representing a total of 163,000 H.P. with a capital ex-

penditure of £10,360,000; as well as forty-four companies, representing 110,000 H.P., with a capital of £9,105,000, or, added together, there is no less than the sum of nearly £20,000,000 invested in electrical undertakings for the distribution of energy from central stations. Roughly these figures represent £63·5 per H.P., installed for municipalities, and £82·5 per H.P., installed for companies, and although one must not enter into controversial questions, one cannot help wondering in passing why municipal undertakings apparently cost so much less to lay down.

Then there are electrical tramway or light railway undertakings, either completed or under construction, with a total of 1,628 miles of single track, with a capital outlay of approximately £16,000,000, and there are 720 miles of other light railways contemplating the adoption of electricity as the motive power. That these tramway undertakings will have a wide influence upon some of the great problems of this country one is convinced, if only in the reduction of the number of slums, and in the improvement of the physique and morale of the busy workers of the nation.

I do not intend to weary you with further statistics; suffice it to say that electricity is now slowly but surely superseding other illuminants, and, as a power-transmitter, other less efficient methods; and already there are railways—if only short and special ones—to which centralised power-generation is being applied to the exclusion of the steam locomotive. Among the future problems with which some of us will have to cope will, I believe, be included the electrical equipment of our great railways.

Recently there has been much energy displayed in obtaining powers to lay down immense generating stations from which electrical energy is to be transmitted over wide tracts of country. I am convinced that if this development be not carefully considered, it may be a serious matter for the whole industrial position of England. Several extensive power-schemes have received the Royal assent. Where there are a number of small towns, each of which with say 10,000 or less inhabitants, and possibly the demand for a network of inter-connecting light railways, it would undoubtedly be a waste of public money to put down separate sets of plant for each little place. In such a case it is probably the most rational method to adopt a station common to them all. But where a town has a population of say 20,000 or more inhabitants, it deserves consideration whether it may not be cheaper and better to instal a local station rather than take energy in bulk from a distant one, and then after transformation to distribute it locally. The all-important advantage claimed for these county stations is an improved load factor; but I fail to see how in the same latitude the summation of a number of small peaks is going to result in an improved load curve; and yet upon this factor all depends. If it be not reached, then the reduced efficiency of a high-pressure system, transforming its pressure locally, and in all probability also converting the current, together with the largely increased outlay on long primaries and sub-station machinery, may be found to give less economic results than several smaller stations situated near the centres of demand, and distributing

immediately into their networks, without transformation. The outlay on local feeders and distributors will remain much the same in both cases.

The efficiency of a direct-current station (that is the ratio of units sold to the units generated) rarely falls below 85 per cent.; whereas a three-phase 6,000-volt station, with an average length of primary of 5 miles, and sub-station transforming and converting plant cannot well be more than 68 per cent. In other words, 25 per cent. more units have to be generated in the second case than in the first. Should the load factor be improved 2 or 3 per cent., will not the less efficiency of, and the extra capital outlay on the big power station, more than counterbalance the advantage gained in the load factor? For some districts—as in Lancashire—where the mills are "as thick as leaves in Vallambrosa," it will be the only known natural and economic means of driving them. But speaking generally it will be worth while to consider carefully each case before huge sums are launched into such an undertaking.

It is most important that electrical supply should be as reliable and continuous as that of water or of gas. The water-supply of a town is not dependent on a number of pumps feeding direct into a pipe system, nor does a gas station supply direct into its mains. Both undertakings interpose reservoirs between the generating plant and the mains, which saves the consumer from the risks attendant upon continuously running machinery.

Improved means of storage seems to me to be a method by which a much-improved load factor, less cost of production, and greater reliability of supply can be obtained. On this account I have always felt that if a direct-current system of distribution is at all possible in any district it is wiser to adopt it to enable storage to be effected either now or at some future period. The cost of a storage battery may be taken (for a seven hours' discharge) at £8 per k.w., and the equivalent in boiler, engine, dynamo, and auxiliaries at £21 per k.w. At the present time the life of batteries does not exceed ten or eleven years, whereas the mean life of a generating plant may be taken at about twenty years. The capital charges on a storage battery, therefore, are practically twice as heavy per k.w. as those on generating plant.

A surprising result will be found if one takes the trouble to prepare careful estimates of two stations, one fitted with generating plant only and the other with only half of the plant installed in the first example, and the remainder absorbed in batteries. The capital cost per k.w. is less in the second case; and might it not be well to go more carefully into this matter, and see whether we cannot adopt storage on a larger scale than now? Then, too, the cost of output is really not so great with batteries—even after making due allowance for the loss of energy and the heavier rate of maintenance. Against the charges is to be put the much-increased output or plant load factor. In traction systems of moderate size also the mean load is but one-third of the maximum, and here again I believe storage will play an important part in the future economical supply of electrical energy. I do not wish to be *doctrinaire*, but I cannot help feeling that *this only* will enable the cost of supply to be reduced to a minimum.

There is another question, viz., the influence of capital costs on cost of production, too often overlooked by some electrical engineers. One finds that, graphically, these represent an hyperbola. Their influence on units sold per k.w. demanded is very great, and they bear an almost constant ratio after the first few years to the units sold, or, put in other words, the capital outlay increases *pari passu* with the units sold; therefore, this part of the total costs after a time is practically invariable. This is important, and it is not difficult to ascertain what the minimum cost of production under the present conditions will be. Again, the other standing costs now are fairly proportionate to the total plant installed, once the station has grown to a fair size. So long as the ratio of day load to maximum demand remains as it is to-day, and we have to provide a maximum of running plant commensurate with the demand, will it be impossible to supply energy at so low a figure as some people hope for. The "Brighton" system of charging is a brilliant attempt to meet this difficulty, and is in my opinion the most scientific method in vogue, but it is not without objections raised by consumers, and is often disliked by them when they get no rebate! Even in this case a round twenty-four hours' supply requires a 1¼d. per unit to meet expenses, without profits, owing to the *dominating influence of the capital charges.* What is likely to be the minimum cost to the bulk of consumers who only average three hours a day? Storage with less costly, more efficient, and longer-lived plates than we have at present, would go far towards reducing the cost of supply, and averaging the cost to all classes of consumers.

I would like to say something to those engineers who may be called upon to design stations. One speaks feelingly as a station engineer oneself. Make your watchword and your guiding principle "Simplicity." Think of the engineer who has to run the plant afterwards from January 1st to December 31st, year in and year out, without an interruption of supply, and with all the responsibility which that entails—arrange simple pipe systems; adequate coal storage; draught, independent of climatic conditions; and switchboards *sans reproche.* Give elbow-room in a station, room for expansion, and do not "crib cabin and confine" the station.

Simplicity shows good design, means economy in first cost, and certainly economy of maintenance. But though simple, let everything be of the best, easily seen, and accessible; and as a station is, so should the mains be. Mains, which in all systems have their weaknesses, are out of sight, and I am afraid very often "out of mind" until an accident happens.

This brings me to another matter which will require most careful thought in the future, viz., the large outlay on mains through which the maximum load is conveyed for only about one hour a day. If one could put a storage battery into every consumer's house, and supply at a uniform rate all the twenty-four hours round from the generating centre, letting the consumer draw off his supply at will (as to a certain extent is the case in the water supply of any house), the mains could be of a far smaller sectional area than they now have to be. To expect such a thing as this is, of course, nonsense, but

if in any given area one places the generating stations as near as possible to their load, the amount of copper required will be far less, of course than when supplied from one station at the same pressure. It will be said if a high-pressure system is adopted, this is but a small item. Is it? Does not the saving in copper in a high-tension system have to be spent on insulation, transformers, sub-stations, and switchboards, and probably converters? The efficiency of distributors will always be low, from the fact that they have to be in every case of moderate potential, and must be of such a section as to cope with the maximum number of lamps connected thereto. They will improve, however, as the applications of electricity become more universal and varied.

A simple system of mains, good both mechanically and electrically, is what should be aimed at. Reliability of supply is most necessary. High-voltage lamps are helping us greatly in reducing the outlay on mains, but even remembering that doubling the pressure on any main of a given section doubles the energy which may be transmitted thereby, and is quadrupled in a three-wire system, compared with a two-wire half-voltage system, I am revolutionary enough to believe that ultimately a plain two-wire system of distribution will be preferable to a three-wire distribution now so universally employed. The effect of the cost of insulation, and the comparatively large balancing wire required in practice—much larger than is demanded in theory—levels down enormously the economy that is said to be gained in a three-wire system; and the effect on the insulation of the negative cable of putting a permanent stress upon it, and that of osmosis, caused by earthing the middle wire, does, as I know from experience, cause a much heavier rate of depreciation on that cable, and the negative service leads—a depreciation which more than counterbalances the economy thought to be gained. Here again perhaps I make a fetish of simplicity, but is it not good engineering to build that which will endure and to give one's clients material which shall be lasting, and at the same time be the best procurable for the least money—in effect the thrifty, but lasting, application of the materials we have to hand? Electricity, like the gods in the elder days of Art, sees everywhere "into each minute and unseen part"—literally does so—and seeing our comparatively short experience of its applications it is necessary to provide systems that will not only be successful at once, but will continue to be so for a generation.

British engineering, if slow in progress, if conservative in policy, is at least recognised as being sound. We are members of a profession which will have an enormous influence on the commercial position of our country. It must be our constant endeavour to uphold the traditions of British engineers, and to develop our industry on sound, broad-minded, and progressive lines.

We have begun our second Session, and it is most gratifying to think how responsive members have been to the invitation of the Committee to provide papers for the section. Important papers on Power Distribution, Polyphase Machinery, Telephones, Legislation in Electrical Matters, Tramways, etc., have been promised, and will, I am confident, conduce to a most successful Session.

This section can do much to aid the development of applied electricity in the north-eastern portion of England, and will, I believe, become an increasingly powerful factor in this work.

The fact that one of our members was accorded a special premium last year by the Council should give rise to a spirit of enterprise among us. I trust we shall have free and useful discussions : thus the improvement of individual members will consolidate and increase the efficiency of the whole section and the Institution, and thereby the whole industry.

Electrical engineers as a body have a great work before them, which must be diligently carried out—our country will depend much, in the future competition with other nations and struggle for existence, upon the economical applications of electricity—for the moment it would seem that we are not keeping pace with our more enterprising cousins and neighbours, and that great schemes are passing into the hands of our competitors. If there is much inertia in the Briton—there is much momentum when he is once in motion. Let us take heart from this knowledge and decide to contribute each one of us his share towards the national need, and to the continued advancement of the great art of Engineering.

GLASGOW LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

Delivered November 19, 1901.

By Professor MAGNUS MACLEAN, D.Sc., Member.

I desire to take this the first opportunity of thanking you for the honour you have done me in electing me your chairman for this current session.

Since we met in May last we have had meetings of a very large number of Scientific Societies in Glasgow, meetings at which papers of scientific importance have been read and discussed. To mention only three of them, the Society of Incorporated Municipal Electrical Engineers met in June last, and the International Engineering Congress and the British Association for the Advancement of Science in September last. At these meetings a considerable number of electrical papers were read. Indeed at the Electrical Section of the Engineering Congress so many papers were prepared at the request of the Council of the Institution, that there was no time given to some of the authors even to adequately summarise them to the meeting, and none at all for discussing some of them. So much electrical information has been thus given to us during the last summer and autumn that you might reasonably expect us to spend this session in digesting it, and not aim at getting more papers read to us. But no. The Committee of this Local Section of the Institution have had offers of papers as usual, and you will have noticed from the circular the Secretary issued to you recently that we have had already promises of sufficient papers for this session. These papers are on a variety of subjects, such as laying electric mains, manufacturing of aluminium, construction of electro-magnets to give very powerful magnetic fields, testing of electrical machinery, etc.; and we trust that in every case these papers will lead to valuable discussions and to the elucidation of difficult and doubtful theories, problems, and facts.

Again we had a successful International Exhibition in our midst. A paper describing and discussing the developments and improvements that have taken place in Electrical Engineering apparatus during the last thirteen years, as illustrated by the electrical exhibits in the 1901 Exhibition, and those in the 1888 show, would be most instructive.

1. *Electrical Generators.*—Generally speaking, improvements have taken place in every direction. In electrical generators the tendency has been towards simplicity of type and uniformity in matters of detail. In continuous-current machines the commutator is becoming standard-

ised both in materials and in manner of construction. Drum-winding is superseding ring-winding, and multipolar machines are almost universal for moderate and large outputs. The open-coil direct-current dynamo was not represented at the last Exhibition at all. Alternating-current generators both single-phase and three-phase were shown by different exhibitors, as well as rotary and static transformers. By means of the latter, one firm was showing the conversion of 500 volts continuous to 10,000 volts three-phase current. There is no doubt that this type of machinery is gaining favour with electrical engineers. Some electrical engineers who, a few years ago, were wedded to continuous-current generation now loudly proclaim the advantages of alternating-current machinery.

2. *Electric Measuring Instruments.*—No greater advance in any department of electrical engineering has taken place since 1888 than in electric measuring instruments. Amperemeters for direct currents are now chiefly constructed on the principle of (1) the electro-dynamic action between two neighbouring coils carrying currents, or (2) the sucking action that a solenoid exerts on a suitably suspended soft piece of iron, or (3) the action of permanent magnets on a suspended coil carrying a current.

There are different methods of balancing the electro-dynamic and electro-magnetic forces; and the most common are (1) the weight of a piece of matter, (2) the torsion of a wire, or spiral, or flat spring, and (3) the couple due to a bifilar suspension. Amperemeters of the hot-wire type and the movable-needle type were not shown to any extent.

Voltmeters of the electro-magnetic type are still in evidence, but they are giving place to other types and more especially to the electro-static type, because the latter consumes no energy and can be used either on direct or on alternating-current systems. Dynamometric wattmeters for direct, for single-phase and for three-phase currents were shown by a number of instrument-makers, also phase-meters for showing the wattless component of the current in amperes. One firm at least had voltmeters, amperemeters, and wattmeters for alternating current which depend on the mutual action of eddy currents in a light metallic pivoted disc, and in a metallic screen which partially shields the disc from the magnetic action. Instruments of the recording type are becoming essential for supply stations. Hence there were exhibited by several firms recording amperemeters, recording voltmeters, and recording wattmeters.

In 1888, electricity supply meters had not advanced much beyond the experimental stage. Now we have reliable meters of all types. The most common types of meters may be classified under four heads, depending upon which property of the current is utilised for recording its amount :—

(1) Thermal meters.
(2) Chemical meters.
(3) Integrating or clock meters.
(4) Motor meters.

To illustrate the proportion of the different meters in use in the

various supply-stations in Great Britain, the following list is collated from the information given by the technical press last January :—

Name of Meter.	Number of Stations at which the Meter is used.	Type of Meter according to the above classification.
Chamberlain and Hookham ...	116	4
Thomson	69	4
Ferranti...	65	4
Aron	41	3
Shallenberger	40	4
Bastian	19	2
Schattner	14	2

Thus it appears that the motor-meters have as yet the preference. Clock meters are, however, increasing in favour on account of the great improvements recently effected on them.

An electric measuring instrument which was not on view in 1888 and was on view in the last Exhibition is an oscillograph. This gives a continuous record of the current wave of an alternator, and by using a double oscillograph the potential-difference curve and the current curve can be simultaneously traced. This instrument gives us a method of studying many problems of alternating-current machinery which were difficult of experimental solution by previous existing apparatus.

3. *Practical Applications.*—The uses and practical applications to which electricity may be put were numerously illustrated. I shall only mention a few of them in passing: Search-light, pumping, surface contact tramways, electric cranes, electric haulage for mining work, electric drilling, electric planing, electric locomotives with overhead supply, electric locomotives with accumulators, motor-driven printing machines, overhead conveyer for carrying luggage in railway stations, electric lifts, electrically driven air pumps, electrically driven ventilating fans, motor driven centrifugal pumps, electrical coal-cutters, electric Jacquard. In connection with the application of electricity to electric lighting, I should mention the Nernst lamp, which was shown in actual operation in Scotland for the first time last September, when Lord Kelvin switched some of them on at the stand of the Electrical Company in the Exhibition. Through the kindness of Mr. Buhler, samples of the Nernst lamp are on the table for your inspection. The material of the filament is composed of one or more of the rare earths zirconia, thoria and yttria, also magnesia. The filament only begins to conduct at a temperature of 500° C. From that temperature to 1100° C. the conductivity increases in the ratio of 1 to 330. To give stability to the lamp a series-resistance of iron is put in, to balance the diminishing filament resistance with increase of temperature. The filament is raised in temperature by a spiral of platinum wire surrounding it, which is in parallel with it and through which practically the whole of the current, on account of the high resistance of the filament,

in the first place passes. When the filament becomes sufficiently hot or sufficiently conductive, and this happens in less than half a minute, the spiral spring platinum is automatically cut out of circuit by an electro-magnet, and the refractory oxide filament becomes incandescent. The efficiency is given at 1·5 watts per c.p. The filament is an electrolyte, and hence when the supply is continuous the current must be put through it in the proper direction. When the lamp is installed for the first time care is therefore necessary in fixing it to the proper terminals. Afterwards the filament renewals are so arranged that they can be put into the lamp only in the correct direction. On an alternating-current supply the lamp can be fitted any way. I am told that the filament lasts much longer when alternating currents are used. I expect a great future for lamps constructed on the Nernst principle.

At the last meeting in May, Mr. Walter Jamieson showed those present some experiments on high-frequency oscillations by apparatus mostly of his own devising and all of his own construction. A desire was expressed that an opportunity should be given to him to repeat some of these experiments and show some others, the apparatus for which he had no time to prepare on the previous occasion. He is present this evening to illustrate experimentally some of the more elementary facts and results of observation and experiment in the subject of electric oscillations.

The first reference we have to the discharge of a condenser being oscillatory is in a remark by Professor Joseph Henry in 1842, and the second reference is in an essay by Von Helmoltz in 1847. The outstanding important date is, however, in 1853, when Lord Kelvin showed that the discharge would be oscillatory or continuous according as R^2 is less or greater than $\frac{4L}{K}$, where R is the resistance, L the inductance, and K the capacity of the circuit, all the factors being expressed in consistent units. Thus when R^2 is greater than $\frac{4L}{K}$ the discharge is unidirectional, and when R^2 is less than $\frac{4L}{K}$ the discharge is oscillatory.

MANCHESTER LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

Delivered November 19, 1901.

By C. H. WORDINGHAM, Member.

It is no formal or conventional thanks that I render to you this evening for the honour which you have done me in electing me Chairman of this highly important Local Section of the Institution, for I appreciate most keenly this mark of your esteem and confidence. I can only say that during my term of office I shall look upon it as a great privilege to do everything that lies in my power to promote the success of the Section.

Our own local interests naturally first claim attention, and I think we may look back with satisfaction at last session, and forward with considerable confidence to the one now beginning, the second which has been held under the auspices of the Institution. Though so new under its present designation, this gathering of electrical engineers from the district of which Manchester is the centre has a past of which we may well be proud. It dates back to 1893, and in its palmy days the papers read at its meetings were so excellent, and the discussions on them so practical and so bright, that there were not wanting those who drew comparisions between the old Northern Society and our own Institution. There was indeed at one time actually danger of rivalry between the two. Happily the possibility of such rivalry has been removed by the generous and wise policy adopted by the Institution, whereby the Council has recognised the legitimate desire of its members to hold meetings in the localities to which their work calls them, and to discuss with their immediate neighbours the problems with which they are confronted. This decision of the Council, the successful execution of which is so greatly aided by the tact and conspicuous ability of our Secretary, Mr. McMillan, cannot fail to have far-reaching effects upon the fortunes of the Institution, raising its status and increasing its importance far above anything that would have been thought possible a few years ago.

It is not only, however, from the point of view of the Institution as an Institution that there is reason for congratulation. There can be no two opinions as to the great importance of having a single organisation resting on a broad and comprehensive basis to represent the electrical industry of the whole British Empire.

It is a recollection of the early days of the Northern Society which makes me feel so confident of the success of our own local section; for we have the same men among us that we had then, and we have in Mr. Cowan an honorary secretary whose competence for the work and energy in carrying it out could not be surpassed, while the inducements

to members now are much stronger than in the days of the Northern Society to prepare papers and take part in our discussions. Our proceedings form part of those of the Institution, and papers, if of sufficient merit, are printed in the Transactions, being equally with those read in London eligible for premiums.

I trust, therefore, that members who are in a position to do so will come forward with papers, and that all will make a point of attending our meetings and taking part in our discussions. Especially do we want the young men, those who so far are unknown, for nothing is so painful as to hear only the same voices meeting after meeting, and not the least so to the speakers themselves, who often take part in the discussion solely because they do not like to see it languish altogether.

One of the great difficulties we have to contend with is the provision of a suitable place in which to meet. Through the courtesy and generosity of the authorities of Owens College, this excellent theatre has been placed at our disposal, and I am quite sure that we all heartily appreciate their action. At the same time there are always some who will inquire into the age of a gift horse, and I have heard rumours of objections being raised, some saying that to meet at Owens is like going to school again, others that the College is too far from the railway stations, and so on. Good as the room is, one must recognise the fact that the college is a little far for some of the members to come who have trains to catch, and perhaps the physical comfort is not quite so great as is to be had, for instance, in the theatre of the Institution of Civil Engineers. Nevertheless, I cannot but think that there has been an enormous gain both as regards the comfort and dignity of our meetings through ceasing to hold them in an hotel, while the facilities for experimental demonstration are of no small value.

It is quite hopeless for the Section, unaided, to provide any accommodation of its own, for we have but a limited grant for current expenses from the Institution, and we could hardly expect the Council in London to make any effort to provide a meeting-place for a local section when the Institution itself is entirely dependent upon the hospitality of older and richer corporations for its own meetings. There does, however, seem to me to be a way in which the difficulty might be solved if only the various engineering and scientific societies in Manchester would pull together. Manchester has long been prominent as an engineering centre, and it bids fair to eclipse all others as a seat of electrical enterprise. The local engineering and scientific societies are at least as important as any out of the metropolis; they are numerous, there being upwards of thirty local societies or branches of London Institutions, and some of them are extremely well provided with funds. At present all these societies meet in different places, many of them in hotels, and the aggregate rent paid in the course of a year must be very considerable. Surely all these Institutions, which have this in common that they are seeking to promote the interests of science in either its abstract or its applied form, might combine together and jointly provide or rent premises which should afford a suitable and convenient place of meeting, and, at the same time, accommodation for their respective libraries.

Manchester as a city prides itself upon being in the van of municipal progress, and its citizens have provided funds for an Institute of Technology, which has been planned to be as near perfection as money and thought can make it. With the opening of this Institute there is being inaugurated a new era in the technical education provided in the district, and the standing to be taken by this new Institute depends very much upon the line of action taken in the early stages. Already there are signs that the authorities desire it to be something more than a mere technical school, and it would seem that an effort is being made to secure this by making the status of the staff as high and dignified as possible. It appears to me that the opportunity exists at the present time of immensely adding to the dignity, and of greatly improving the position, of this Institute, by the authorities stepping in and bringing together under its wing the various societies and affording them that material assistance which many of them lack, while receiving in exchange the support and weight of all that is best in the scientific and engineering circle of the district. I raised this question some six months ago at a meeting of the Society of Chemical Industry in Manchester, and, judging from one or two paragraphs that have lately appeared in the newspapers, there seems some prospect of such a scheme being considered, and I sincerely trust that it will receive the hearty co-operation of all concerned. It is my intention to bring this matter before the Committee of this section at the earliest opportunity, and I hope that by our united efforts some effect may be produced, and that we may be able to report to you that our negotiations have been successful.

I have referred to the libraries of the local societies, and I think that the want of a thoroughly good technical library is one severely felt in Manchester. In London there are the magnificent libraries of the Institution of Civil Engineers and the Institution of Mechanical Engineers, while for purely electrical work that of our own Institution is not to be excelled ; but we in Manchester are cut off from the advantage of these libraries, and practically there is no place to which we can go and find the books that we should like to refer to from time to time. We cannot even find the technical papers at our disposal. Many of the local societies have libraries of considerable value, but they are locked away in bookcases in the public rooms of hotels, and are by no means readily accessible. The modest library of our own Local Section is at present housed in a bookcase accommodated out of charity by one of our members. If only these books could be brought together in one place, and each society would throw open its library to the members of all the others, the gain all round would be enormous, and there would be a strong incentive to improve and add to the joint library if it were felt that it were of real use to members.

Closely allied to the subjects to which I have referred is one that has been mooted on more than one occasion—namely, the promotion of social intercourse among the engineers of the district. None of the existing clubs can at all be looked upon as being particularly affected by engineers, and such as are political are by their nature unsuitable. It has, therefore, been suggested that a purely engineering club should be

formed, and the further suggestion has been made that accommodation for the holding of meetings might be furnished in connection with such a club. For my own part, while heartily approving of the idea of the club, I do not think that it would be found desirable to combine it with the engineering societies themselves. It would in my opinion be far better that the two problems should be dealt with each in its own way, and that the highest possible standing should be taken by the institutions charged with the furtherance of science and engineering, and I sincerely trust that some such way of promoting their common interests as I have indicated may be found.

There is one other subject of local interest to which I desire to refer, namely, the question of students of the Institution. In the days of the Northern Society, this class was practically non-existent, but now that we are a branch of the Institution, there are naturally a number of student members entitled to attend our meetings, and this class has been substantially augmented by the joining *en bloc* of a society promoted under the auspices of Mr. W. H. Gee in connection with the pupils at the Technical School. There must be a large number of young fellows who are receiving their education in the important engineering works of the district, and considerable numbers cannot fail to be attracted by the new Institute of Technology, so that we may look forward to a substantial growth in numbers of this class of member. All of us who have been students of the Institutions in London, particularly of the Institution of Civil Engineers, must have felt what an immense benefit was derived by us from attending the students' meetings organised by these Institutions. It is, in my opinion, difficult to over-estimate the educational value of preparing papers to be read at such meetings and of the training in debate afforded by taking part in the discussions. I look forward to the Committee being able to organise, even with the present numbers, meetings of the kind, and I hope that it may be found possible to make arrangements for visits to works of interest during the session.

Leaving now matters of merely local interest, I turn to the main object of my address, and I am bound to confess that I feel a difficulty, which it is some consolation to reflect is common to the writers of most inaugural addresses, in choosing a subject of interest. A review of engineering progress is only of use when undertaken by a master hand, and by a veteran who has borne the burden and heat of the day in the battle of engineering development, while it is not given to many of us to have the leisure or the opportunity for conducting scientific researches which may result in discoveries of a startling or epoch-making character. I have, therefore, thought that some slight comment upon one or two of the general questions which are agitating the minds of so many engaged in electrical enterprise might form perhaps the most suitable subject for this address, and I must rely upon the indulgence of my hearers in respect of my shortcomings, both as to completeness and novelty.

We are now passing through an extremely critical period in the development of electrical engineering in this country, and much depends on the attitude assumed by every individual member of the

profession. The stage in which electricity was untried and its usefulness doubtful has gone by, the day of small things is over, and we are entering upon a new phase of development in which the science is invading the domain of the heaviest class of mechanical engineering. Are we prepared for this development? Are we fit to step forward and say the demand exists in our country, we are prepared to supply it? If one may judge by common report, we are not. The undoubted fact is pointed to that contracts for large works are awarded to American and Continental firms, and the inference is drawn that English makers are unable to undertake them and are either behind the times or incompetent.

This charge is a serious one, and, if well founded, means not only that British Electrical Engineers are a failure, but that the decadence of the engineering industry of this country has set in, for what branch of engineering has not now been made electrical in some measure? Let us examine a little more closely the common report. Whence does it emanate? Largely, no doubt, from the daily press, which is so anxious to obtain a sensation that it does not pause to consider the mischief that may be wrought by propagating it. Unsupported, the Press would probably not do much real damage, but unfortunately electrical engineers themselves seem to be but too prone to lend colour to the story of their own incompetence; while the fact that their foreign competitors are successful in securing contracts is, to the lay mind, convincing proof of the latter's superior fitness to carry them out.

It appears to me that all unsuspected the British nation is the most polite upon earth. When an English engineer goes abroad he seems to feel it incumbent upon him to express amazement at everything he sees, to praise every detail of the plant or works he inspects, if it differ from what he has been used to, without stopping to inquire whether it be better or worse, while he freely expresses his astonishment at some system of working that he is unfamiliar with, though it is more than likely that, had he been called upon to solve the problem, his own old despised methods would have afforded a solution twice as good as the one on which he lavishes his praise. When our Englishman comes home he makes pessimistic speeches, eagerly reported by the daily press, as to the marvellous advance made by foreign nations, belittling his own achievements and those of his colleagues, and for months he fills his technical papers with absolutely gratuitous fully illustrated advertisements of his rivals' works. Truly the politeness of the Englishman is magnificent, though some of us may think it is not trade, and that the words addressed to King Lear are applicable to him—

"Thou gavest them the rod and put'st down thine own breeches."

But the stay-at-home islander is not to be outdone by his travelled brother; he has specifications to draw and plant to purchase. What is the blackest crime in his eyes? A preference for native-made plant. The mere suggestion that he has such a preference at once raises the blush of shame. No, he is no spread-eagle or jingo; he does not think the nation whose name in foreign markets is a guarantee of genuineness and good quality is any better than others, and he will gladly waive his

most cherished conditions in order to give an extra chance to the foreigner and thereby show that he is a "Citizen of the World," forgetting that—

"That man's the best cosmopolite
Who loves his native country best."

If, then, the engineers themselves eagerly praise their rivals, can we blame the man in the street if he assumes the inferiority of his own countrymen to be a fact, for he could never guess that their self-depreciation arises from politeness and modesty. But, you will say, why do the contracts go abroad? If the work can be done here, why is it not? That is a question which cannot be answered in a word because the reasons are manifold and varied.

In many cases, no doubt, the work has been done for less money, and we will assume that it has been done as well as if the contract had been in English hands, though this assumption is, in many cases, far from the truth. Are we justified in drawing the deduction that because the machinery, or whatever it may be, is sold for less, therefore the foreign manufacturer has produced it at less cost than we, thereby showing that his practice is in advance of ours. By no means; it must be borne in mind that the English market is a comparatively new one to foreign makers of machinery, and the merest tyro in commerce knows that in order to push his wares he must advertise. Advertisement necessarily costs money, and the payment may advantageously take the form of a discount on the goods first sold. For not only are they thereby brought under the notice of possible future buyers by the very fact of being got into the country, but the trade is actually begun by the very fact of lowering the price. It is an old device, but it never fails. Men always have sought for bargains and always will. The Nemesis comes later.

Again, over-production and industrial depression in the producing country has, undoubtedly, had much to do with the low prices of some of the plant sent into the English market, manufacturers being ready to sell at almost any price rather than discharge their hands and admit the rotten condition of their trade.

Low price is not, however, the only consideration that has determined the award of contracts for electrical machinery out of England; promises of early delivery have been almost, if not quite, as potent. The purchasers will procrastinate for months or years, allowing every trivial matter to delay them, but once they determine to go forward their lethargy is exchanged for panic and unreasoning haste. Here again, over-production enables the foreigner to secure many of the contracts which in this case are often awarded to him regardless of price because he can promise early delivery. The purchaser never considers that other contracts which must be executed first cannot, by their very nature, be carried out in so brief a period, and he finds subsequently to his cost that the plant, for which he has paid more than he would have had to pay to an English firm who required a reasonable time for delivery, is on his hands deteriorating and costing him heavy sums for demurrage. Meanwhile there has been the usual cry of the

vastly superior resources of the foreigner, and the mischief has been done to the English manufacturer—mischief which is unremedied because the public never hears the end of the tale.

I ought perhaps to touch upon the question of the relative quality of the British and foreign-made machinery. Let us at once grant that much of the latter is excellent, while, at the same time, it must in common fairness be admitted that much is unconscionable rubbish. Do we, who are in daily contact with British machinery, honestly believe that our manufacturers are in any one respect incapable of making as good machinery as any imported in this country? Do we not know that from British workshops is turned out machinery that it is impossible to better, whether in design, in workmanship, in finish, or in durability? And do we not know that our alleged inferiority is a delusion?

In the past, English engineers have been in the forefront. An Englishman, nay, a Manchester man, John Hopkinson, taught the whole world how to build dynamos. The earliest attempts at heavy electric traction were made in this country. An Englishman, Ferranti, first conceived and executed the idea of commercially working at high pressure and devised the means whereby it might be done with perfect safety. An Englishman, Hughes, gave to the world the invention which made long-distance telephony possible. By the invention of an Englishman, Swan, domestic electric lighting became an accomplished fact, while English engineers have carried out almost the whole of the submarine cable work of the world. With this record behind us, is it likely that we shall cease to be in the van? Most assuredly not, unless our fellow-countrymen take the heart out of us by ceasing to believe in our capacity and by belittling our achievements.

I do not wish my remarks to be misunderstood. I do not for one moment seek to imply that good work is not turned out from foreign workshops or that we as a nation have any monopoly of engineering skill. On the contrary, I yield to none in my admiration of the splendid achievements of our American brethren and of other nations more distant in blood but nearer home who are following in their steps. I have merely endeavoured to show that the position at the present time really is that English makers are fully equal to their competitors, but they are being driven out of their home market, not because their rivals can produce better, more cheaply or more quickly than they, but because these competitors are willing for a time to undersell them, while over-production enables them at present to forestall them.

We have seen that no help is to be expected by English manufacturers from their colleagues. What, then, are they to do? I do not presume to suggest a remedy, but it does seem to me that whatever it may be, one thing is certain—they must join hands and combine, not, as has been done in many branches of commerce, to raise prices, but to lower them and so drive away the competitors who now menace their very existence, even though for a time they should be forced to face exceedingly lean times. Unless they do something drastic, and do it quickly, they will find themselves, to use a cant phrase, "frozen out," and the foreigner will be master of the situation. Then will the pur-

chasing public in vain seek for the English competitor, and bitter will be the repentance of the present cupidity.

Having extolled our virtues as electrical engineers, it is only right that I should turn to our faults. It seems to me that two stand out prominently. One is a tendency to rush to extremes, the other is a want of foresight. The former of these faults showed itself in the early stages of the industry, one of its most noteworthy manifestations being the once notorious conflict between the advocates of high-pressure alternating and low-pressure continuous current; feeling actually ran high over such a purely technical matter, but now controversies involving wide issues are conducted with positive acrimony and the views are as extreme as those held by opposed political parties. Indeed some of the controversialists have forgotten the traditions of science, and have descended to invective, misstatements, and other discreditable weapons of the hustings.

There seems an entire absence of a judicial attitude of mind, and it is rare to find on either side the admission of the possibility of reason on the other. One example will at once occur to every one, namely, the question of municipal *versus* private enterprise. In its essence this is a purely political consideration, and with politics, and their attendant prejudices and intrigues, it is well for engineers to have nothing to do so far as their work is concerned. To some of us it may seem that Tennyson's words have a wider application than that implied by their context, that—

> "Our little systems have their day,
> They have their day and cease to be,"

applies to all forms of government, that all are "broken lights" of true and equitable rule, and that probity and uprightness in individuals are far "more than they." In other words, that people may be justly and well governed by the unbridled autocrat, and by the latest socialistic community, provided that in each case the individuals bearing authority are single-minded and seek the good of the governed.

Be this as it may, it cannot be denied by those who have had experience of undertakings managed both by a board of directors and by municipalities that both can attain excellent results, and that both can produce abject failures. It is no more fair to brand every member of a municipal council as a "Bumble," a fool, a seeker after his own ends, and blinded by prejudice, obstructiveness and ignorance, than it is to look upon every member of a board of directors as an unscrupulous company promoter, a selfish grabber of dividends, and an enemy to the public. Both views are absolutely unjust; and able, upright, conscientious, and straightforward men will be found directing the operations of both classes of undertaking.

No fair-minded man can deny that some local authorities have adopted tactics of the most unfair obstruction, and have sought to prevent others carrying out work which they themselves have refused to do; but, on the other hand, it must equally be admitted that some companies have been worked solely in the interests of the shareholders without any regard to the welfare of the public; while others, in order

to gratify the greed of the promoters, have been overloaded with capital to such an extent as to render it impossible for them to satisfactorily serve the public.

Having glanced at the extreme views so constantly reiterated, let us endeavour for a moment to look at the question impartially. Judged by results, as shown by the returns in the excellent manual compiled by Mr. Garcke, who certainly cannot be accused of unduly favouring municipal enterprise, the municipalities have done better than the companies, for they have made a profit on their capital only one-half per cent. less than the companies, while the average price they have charged is over 22 per cent. less. The subject must, however, be considered from other points of view, for the side issues are of far-reaching importance.

Admitting for a moment the principle of municipal trading, what is its proper sphere, and what are its limitations? for very few, except professed communists, would advocate its indefinite extension. The city of Glasgow may be looked upon as the apostle of municipalisation, and therefore, in order to find the case fairly stated from the municipal point of view, I cannot do better than quote the Lord Provost of that city. In defining what, in his opinion, were the conditions necessary to render an industry a proper one for a municipality to take up, he stated that it must be monopolistic in its nature, must be a necessity for the inhabitants of the district, and must cause interference with the streets. Such a definition, while allowing a large field for municipal enterprise, imposes well-defined limitations. For example, it effectually cuts at the vicious principle of municipalities becoming manufacturers; by no possibility can any kind of manufacture fulfil all three conditions of being a monopoly, a necessity, and of causing interference with the streets. If municipalities stop short at the point indicated, and confine themselves to employing plant manufactured by private companies, and using it for the supply only of public necessities, the manufacturing portion of the electrical engineering profession, at all events, has nothing to lose and everything to gain by the establishment of undertakings for which capital is found at a low rate of interest.

The danger, however, cannot fail to be ever present that the bounds will be overstepped. For example, a large tramway undertaking must of necessity have extensive repair shops for both its cars and its motors. How great will be the temptation to keep these shops busy by making new cars and new motors? It is sound policy from a purely trading point of view, and those responsible for the financial success of the undertaking would be more than human if they let ideal considerations of the ethics of municipal trading stand in their way. It is this danger of overstepping the bounds that leads many to disapprove of all municipal trading on the principle actuating the ardent temperance reformer when he will have nought of the moderate drinker; but less prejudiced persons hold that, if a thing is good in itself, it is a pity to condemn it for fear of abuse.

However satisfactory properly regulated municipal trading may be to the manufacturer, there are other issues affecting the industry generally that cannot be so regarded. The charge is often brought against

municipal undertakings that they are of necessity parochial in character, and that in consequence, unless private trading is introduced, no large schemes such as those of power distribution or comprehensive tramway schemes can be worked. This contention is based on two fallacious assumptions. In the first place, there is nothing to prevent local authorities combining for a large scheme. An example of such combination for lighting and power supply is seen in Manchester, where some eight or ten neighbouring authorities have agreed to take their supply of electrical energy from the city, while an even larger scheme for the tramways has been successfully negotiated if one overlook the temporary secession of Salford. The second fallacious assumption is that with trading companies the parochial difficulty will disappear. Those who have tried to arrange comprehensive schemes find that the difficulties of satisfying all requirements often prove insuperable, and the enterprise has to be dropped.

That there are inherent weaknesses in municipal management cannot, I think, be denied, and first among these I should place the liability to an entire change in the constitution of a committee, not on account of any inability to manage the undertaking, but purely from political reasons. Nothing can be worse for any undertaking than sudden and erratic changes of policy, and this want of continuity often produces disastrous results. A most noteworthy instance occurred recently in a metropolitan district in which an extensive and useful lighting and tramway scheme was projected, carried through its initial stages, and then, owing to a change in the constitution of the committee, suddenly dropped.

Next, the large size of most municipal committees tends greatly to hamper the work and to preclude the prompt action necessary in commercial undertakings, while the class of man preponderating on town councils tends each year to deteriorate, and men whose business is confined to the keeping of a small shop find themselves called upon to direct large undertakings requiring for their conduct a very Napoleon of commerce.

Again, there is a fatal tendency on the part of members of municipal committees to seek to shine as technical experts, often deriving their knowledge from some friend who has a smattering of the subject. These men insist upon interfering with their paid advisers, frequently marring their carefully thought-out plans.

Lastly, there is the danger—and it is a very serious one—of political considerations being allowed to influence the policy of municipal trading committees. More especially is this the case where any question of labour arises. Many members are in abject terror of the working-class vote, and will go to almost any length to avoid losing it, with the result that the undertaking is severely handicapped.

Other charges, such as a tendency to corrupt practices, to favouritism of individuals, and so forth, are frequently brought against municipalities, but the tendency to these vices is inherent in human nature, and is quite as rife among directors of public companies as among members of municipal committees.

In spite of the drawbacks I have enumerated, excellent results, as we

have seen, are produced under municipal management, and the reason for this is, I think, to be found in the class of man who has been attracted to the work. Municipal electrical engineers have shown themselves to be of quite a different stamp to the proverbial municipal official, and as a body they have displayed a spirit of independence, a keen enthusiasm for their work for its own sake, and an ardent desire to improve their undertakings in every possible direction. Central station practice owes much to municipal engineers, and one cannot but contrast the open manner in which they publish their results and experience with the policy of secrecy pursued by most of the officials of public companies, who have fallen very far short of the ideal set up a good many years ago by Colonel Crompton, who was, I think, the first to urge upon electrical engineers the necessity for full publication in the interests of the industry at large—a doctrine which he was one of the first to put into practice.

Let me now leave this instance of the tendency to rush to extremes, and turn to another in which zeal has been allowed to outrun discretion and common sense. During the past year much commotion has been caused by the action of certain gas and water companies in the matter of possible danger from electrolysis arising from the operations of traction systems. The tendency mentioned has been evinced by both parties to the controversy. On the one hand, the gas and water companies, not satisfied with protecting their property, have sought to impose conditions which would make it commercially impossible for electrical engineers to carry out their work, while on the other, electrical engineers have sought to repudiate responsibility altogether.

Let us look at the position impartially for a moment. Immense sums of money, belonging to communities or to individual shareholders, are invested in gas- and water-pipes laid underground, on the due maintenance of which depends the distribution of such a vital commodity as water and of such a universally employed agent as gas. There arises a new industry which necessitates the passing of electric currents through the soil in which these pipes are laid. It is known that under certain conditions these currents may damage the valuable property already in existence. Is it to be wondered at if those responsible for such property become alarmed and seek to insure themselves against loss if damage should occur? It is urged that if the promoters of electric traction comply with certain arbitrary regulations drawn up by the Board of Trade when the state of knowledge of the subject was far less complete than now, they should be exempt from all liability for damage caused, no matter how great this may be. Is this position consistent with common fairness? The gas and water companies have, with the sanction of Parliament, expended their money in order to meet public wants. Is it just that another company, which no less, but no more, than they, serves the public, should be allowed to conduct its operations in such a manner as to destroy their property. All parties should be granted the free use of the soil, but no one of them should be allowed to damage any other.

Surely, the only reasonable position is that the traction companies should be allowed to carry out their work in the manner sanctioned by the Board of Trade, but if damage can be proved to have been done by them then they should bear the cost. If the traction companies have

the confidence in the Board of Trade regulations which they profess to have, they surely cannot object to this, because they will do no damage. On the other hand, if they do the damage they ought to pay for it. It is objected that many bogus claims for ordinary corrosion will be made on the electrical companies; this may be so, but, after all, the onus of proof of damage lies upon the gas and water companies, and the electrical engineering profession has not hitherto proved itself lacking in either ingenuity or ability, and may safely be relied upon to take care of itself. At all events, such a consideration ought not to affect the broad question.

In this controversy the disastrous effect to electric traction generally that would arise from a wholesale destruction of gas- and water-pipes, if such destruction should take place, seems to have been lost sight of, and I venture to think that those who point out the danger and enforce attention being paid to it now are far greater benefactors to the profession than those who vociferate that there is no danger, and urge on traction companies to what might be ultimate ruin. There is no doubt that if the danger is recognised now, it can very well be avoided, for a much lower limit of drop of potential than that allowed by the Board of Trade can easily be worked to.

The second of our failings to which I have alluded is a want of foresight. A striking instance of this is the recent extensive promotion of Bills for the establishment of companies to generate electrical energy and distribute it over large districts. I do not wish for the moment to say one word upon the merits of these schemes. No doubt there are circumstances under which they may advantageously be undertaken, while, in other instances, it is difficult to see any justification for them. In any case, however, it is certain that they will require for their carrying out enormous quantities of plant of very large calibre. This demand is suddenly sprung upon our manufacturing firms; can we expect they will be ready to undertake the work? Surely the better plan would have been to provide the capital first to extend existing companies, or even to establish new ones for making the plant, and then to have promoted the power companies to purchase this plant.

Looking at the subject from a commercial point of view, there is after all but little advantage to the electrical industry as a whole in extending the use of electrical appliances if the manufacturers cannot share in the development. I greatly fear that the course adopted will result in the orders going abroad through the unfortunate want of foresight in thus putting the cart before the horse, the labour and enterprise expended by the promoters of the schemes availing thus only to increase the prosperity of our commercial rivals.

I might adduce many examples of want of foresight, but I will only allude to one other which has particularly struck me, probably on account of my long connection with central-station work. I refer to the way in which central stations are so often designed. In the early days of public supply it was not surprising that the demand should be underestimated, and stations be put down on a totally inadequate scale, but now, in the light of accumulated experience, it is astonishing to see the initial instalment arranged for apparently without any regard to future

increase, or if such increase be allowed for at all, it is of extremely limited extent. Over and over again one sees designs such that it is physically impossible for the station to grow, and within a few years an entirely new station will have to be provided. Only a few months since I read a description of a station concerning which, it was naïvely remarked, that the first instalment, in which a capacity of 1,000 H.P. was allowed for, would be self-contained and independent of further extensions later on, as though this were a merit of the design! and this in face of the efforts that are being made to centralise supply even at the expense of costly long-distance mains. The two self-contained stations might almost as well have been a couple of miles apart as far as cost of management is concerned, while there would have been the benefit of such advantage as might arise from cheapening the distribution. In the same station the entrance to the repair shop was through the battery-room!—more want of foresight!

In concluding this address, time will only admit of my touching very briefly on one or two of the problems most likely to occupy our attention in the near future.

One matter which was mooted in the very early days of the electrical industry has come into great prominence in this country during the last two years, namely, the supply of electrical energy over large areas including small and scattered towns and villages. It does not appear, however, as though the method by which this is to be accomplished has received the consideration it deserves. In place of the problem being gone into thoroughly, it seems to have been assumed that a few enormous generating stations, supplying in some cases to distances of twenty miles, must be the right thing, and there has been vague talk in which coal, gas engines, gas producers, recovery plant, revision of Board of Trade regulations, and so forth have figured obscurely.

These hazy ideas, eked out with violent vituperation against every one venturing to offer opposition, have given the impression that the difficulties have all been solved, and that it only remains to carry out the work. No explanation has been vouchsafed as to how the superposition of a number of similar demands, each with a low load factor, is going to give as a resultant an improved load factor, or why a number of inherently unprofitable towns, when connected together by mains the interest charges on which represent a large proportion of the total probable revenue, will be converted into a gold mine by the use of the magic words, "supply in bulk."

Granted that gas engine driving with producer gas in conjunction with recovery plant gives the cheapest production of electrical energy, what evidence have we that such engines will enable alternators to be run in parallel satisfactorily under working conditions? and it must be borne in mind that long-distance transmission must almost of necessity be by alternating currents. Recovery plant no doubt gives excellent results on a 100 per cent. load factor, but its successful working requires nice adjustments among all its parts, and its capital cost is high. What will be the effect of the sudden fluctuations of demand incidental to a central station, and how will the question of cost be affected when the interest charges have to be earned in an actual

station with a load factor very much below 100 per cent? Again, is it remembered that in order to get the steam necessary for the recovery plant at a low cost about one-fourth of the generating plant must be run by non-condensing engines, and this proportion must be preserved at all loads?

I do not say that these difficulties cannot be surmounted; I think they can; but I do say that we have heard little of the way in which they are to be met, and that meanwhile great mischief is wrought to less ambitious schemes by the Utopian pictures which have been presented to the public of power supplied to consumers at prices no greater than the actual cost of generation, the cost of distribution and other essential charges being left out.

That gas engines driven with producer gas will in the future supplant steam in electrical generating stations there can be very little doubt, but their use will not be confined to stations of abnormal size, for their inherent advantages are very great. The consumption of fuel is but little more than half that of steam-driven plant, and the cleanliness and compactness of the system, coupled with the reduction of radiation and stand-by losses, render possible great strides in the direction of cheapening electrical energy even in very small stations.

There is one method of supplying small towns and villages which has not, I think, been put forward, but which might prove a cheap and easy solution of giving to them the advantages of electrical energy. There are few towns so small as not to have gasworks. Why should not the gas company establish producer plant and sell the gas to a locally-formed electrical company or to the local authority to use for driving electric generators? I should deprecate the gas company undertaking the electrical portion of the business themselves, partly because their staff would not have the necessary experience, partly because they would be tempted to stifle the electrical work. On the other hand, if the course I suggest were taken each portion of the work would be looked after by those most competent to deal with it, and it would be to the interest of both parties to make the electrical undertaking succeed, for the gas company could make as great a rate of profit on the producer gas as on the ordinary lighting gas, while still enabling the electrical company to produce cheaply.

In considering this matter it must not be forgotten that the preparation of producer gas for gas engines is by no means a simple matter, and if to this be added an ammonia recovery plant a considerable amount of skill is required on the part of those looking after the manufacture. This skill is available in gasworks, and for this reason it would pay to put down recovery plant for producers working on a much smaller scale if the operations are carried on in connection with such works than if the plant were isolated.

This extension of the gas company's make would not be at the expense of their existing business, for it is a matter of experience that the introduction of the electric light sets a higher standard of illumination, and actually increases the demand for gas for ordinary purposes, hence the introduction of the electric supply would be a clear gain to the gas company.

Gas engineers who are not wilfully blind to events must recognise that the public likes electric light and power if it can get them at a reasonable cost. It would be far wiser for them to accept the inevitable and, by joining hands with those they now look upon as enemies, participate in this new outlet for their enterprise. Electrical engineers on their part would do well to recognise that gas engineers can help them, and to invoke their assistance in the application of gas for the production of electrical energy.

Perhaps the most important question of all at the present time is what has been infelicitously called the "electrification of railways;" that is to say, the application of electrical energy to the propulsion of ordinary railway trains over long distances.

Electric tramways have now become firmly established in this country, and there can be little doubt they will shortly become practically universal. The horse as a rival was easily beaten; the steam locomotive is one more difficult to displace, but the problem is already being vigorously attacked, and it looks as though for underground railways the battle is already won. The invasion will not, however, stop here, and already the application of electric traction to the main lines of railway is receiving serious consideration. What the result will be is by no means certain, but the present tendency to higher speeds is wholly in favour of electric traction. Though there is unquestionably much yet to be worked out as regards details, the future is distinctly promising.

This problem is in reality closely allied to the one to which I have already referred, namely, the supply of electrical energy to large areas of country, and the satisfactory solution of one problem will go far to help that of the other. Much depends upon the question of the pressure of supply to the motors on the trains, and on whether direct or alternating currents will be the more satisfactory. These are matters that must be gone into closely in each individual case with full data, but that a solution will be found can hardly be doubted.

I am compelled to leave untouched many matters that I might well include, but I have already trespassed far upon your patience, and I will therefore conclude with the expression of a hope that the Session before us may be full of profit and interest to our members, and that many of the matters which I have so briefly touched upon will be fully discussed and ample consideration be given to widely differing views.

BIRMINGHAM LOCAL SECTION.

ABSTRACT OF THE ADDRESS OF THE CHAIRMAN ON THE OPENING OF THE SESSION, 1901–1902.

Delivered November 27th, 1901,

By Principal OLIVER LODGE, F.R.S., Member.

ON "SELF-INDUCTION."

(*Reported from Shorthand Notes.*)

Those present would be aware how great a part self-induction played and must continue to play in the development of their science; how important it was both in theory and practice. He did not hesitate to say that, after resistance—and it might be even before resistance—it was the most important idea in electrical science. Self-induction was a fundamental property of electricity, and its true and full recognition was essential to the treatment of alternating and fluctuating currents of any kind. It had revolutionised the theory of lightning conductors, and it was likely greatly to improve, if not revolutionise the sending of telegraph messages through long submarine cables. The early theory of submarine cable signalling, due to Lord Kelvin in the 'fifties, left self-induction out of account. Now it had been introduced into the theory, chiefly by Oliver Heaviside: but the full importance of it from a practical point of view had not yet been realised nor applied in practice. Whether it would be possible, he did not know; but if it were possible, it would be the only way, as far as he saw, in which long-distance submarine telephony would be practicable. One could telephone great distances overland, but when a submarine cable was included in the line, the voice got wiped out; and the remedy was the proper application of self-induction or electrical inertia.

The idea of self-induction was one which was more familiar to the younger members of the engineering profession than to the older ones. The name "induction" was used by Faraday in a simple qualitative sense, meaning little more than the inductive "influence" of one conductor on another. But Clerk Maxwell gave it a perfectly definite mathematical significance. The induction of a circuit signified in Maxwell's works the number of magnetic lines of force effectively threading the circuit; and the number of lines per square centimetre, or per square inch for that matter, was the induction density: commonly denoted by B.

The number of lines effectively threading a coil of n turns of area A

whose axis makes an angle θ with the direction of the lines is—
$N = B \times$ effective area $= \mu H . n A \cos \theta$., where μ was the average permeability of the medium surrounding the coil. If the lines were due to current flowing in the coil, their number was the quotient of the magnetomotive force, $4\pi n C$, by the resistance offered to the passage of magnetic lines ($l/\mu A$ + similar terms). If, therefore, l and A stood for the average effective values of the length and area of the magnetic lines, this quotient for unit current was $4\pi n \mu A/l$. This number might thread through n' turns of another circuit close by, in which case the coefficient of mutual induction was $M = 4\pi n n' \mu A/l$. But they must thread through the n turns of the original coil, whose coefficient of *self-induction* was therefore $L = 4\pi n^2 \mu A/l$.

Our electrical machinery was all based on Sturgeon's or Arago's electromagnetic discoveries on the one hand, and on Faraday's discovery of electromagnetic induction on the other. The fundamental law of electric motor machinery was $dW = C . dN$; expressing the work done when a conductor, carrying a current C, cuts lines of magnetic force. And the fundamental law of the dynamo was expressed by $e = \frac{dN}{dt}$, viz., that the induced electromotive force was the rate of cutting of the lines.

Returning to the expression for self-induction, it was seen to be μ times a length. They would often find it stated that the capacity of a Leyden jar or condenser of any kind was a length, that the self-induction of a conductor was also a length, and that resistance—and this was no doubt the most familiar—was a velocity. He was sorry to say that some great authorities used to preach this doctrine long ago, to his own and others' great confusion. But he gradually came to see that resistance was not a velocity, nor was either of the other quantities a length. Electrical resistance was not a mechanical thing at all; neither was self-induction or capacity. Resistance was μ *times* a velocity; and self-induction μ times a length. But what μ was we could not yet say. That was one of the things they had got to learn. It was the great discovery next to be made in electrical science. Not only did they not know the numerical value of μ, they did not know even the meaning of it; they did not know for certain what *kind* of a thing it was. He himself believed it to be a density; and in that case it would be measured in grammes per c.cm. or in pounds per cubic foot.

Why was such great stress laid on self-induction? Because it was a property of electrical conduction which you could not possibly avoid. You could not have a current without its being surrounded by concentric circles of magnetic force, and this field was essentially self-induction. Resistance might be called an imperfection of electrical conductors. But self-induction was independent of material conductors, it applied equally to a perfect conductor: it was a property of the space around it.

Resistance, then, was μ times a velocity, and self-induction μ times a length. Similarly capacity was k times a length, k being the dielectric constant, the quantity introduced by Faraday in the 'thirties.

μ first appeared in the writings of Lord Kelvin in the 'forties. These constants μ and k were assumed to be unity for air, for lack of better knowledge.

There were three forms which the electrical energy in a circuit might take: (1) The static, measured by $\frac{1}{2}$ Q^2/S, S being the capacity of any part of the circuit holding at any moment a charge Q. This quantity was known to Franklin. (2) Energy lost in frictional dissipation, $R C^2 t$, a quantity first investigated by Joule. And (3) kinetic energy, $\frac{1}{2}$ $L C^2$, known first to Kelvin and Helmholtz. The first part of these forms was like the energy of a wound-up spring; the second was a frictional loss appearing as heat; and the last was analogous to the energy of a flywheel or other mass in motion ($\frac{1}{2}$ $m v^2$).

If we examined these three quantities, we should find there was no need to call any of them electrical. They were all energy expressions. For example, C^2 was measured by a force divided by μ, giving $\frac{1}{2}$ $L C^2$ as (μ × a length) (force /μ), or force × a length, = work or energy; real mechanical energy.

There were next three time constants of which he would speak. There was (1) the time during which all but $\frac{1}{e}$th of the original charge would leak out of a condenser. This could easily be shown to be equal to the capacity of the circuit into its resistance. $T = S R = (k \times \text{a length})\,(\mu \times \text{a velocity})$, which turned out to be an actual time, expressible in seconds or days or weeks, because the product $k \mu$ was the reciprocal of the square of a velocity.

We did not know the nature of either the dielectric constant or the permeability by itself, but we did know what their product was. One of the most brilliant of Clerk Maxwell's discoveries was that the product $k \mu$ determined the velocity of propagation of electro-magnetic waves in such a way that $k \mu = 1/v^2$.

This expression S R for the time constant embodied the elementary and original theory of telegraphs. For as both the capacity and the resistance of a cable increased directly with the length, the retardation ($T = S R$) of the cable increased with the square of the length. If you doubled the length of a cable you quadrupled the difficulty of signalling through it. The first Atlantic cable was five times as long as any previously laid down, and it was twenty-five times as hard to work.

(2) The second time constant was that which controlled the rate of rise of a current, $C = \frac{E}{R}\left(1 - e^{-\frac{R}{L}t}\right)$; and was measured by the quotient of the inductance by the resistance, L/R. If the inductance is taken in henries and the resistance in ohms the ratio is expressed in seconds. You could not suddenly start a current in a circuit, and the more self-induction the circuit possessed the more time was necessary for the current to start. Starting a current in an inductive circuit was like setting a heavy mass in motion—like the starting of a barge in a canal. The law of starting a barge is mathematically the same, and the same curve of speed-increase applies.

Dr. Lodge illustrated inertia by a model consisting of four 50-lb.

weights on a platform mounted on rollers. A strong cord was snapped in the effort to start the weights suddenly; whilst a single thread would easily set them in motion if only time were taken. And it was pointed out that a steady current, like a steadily moving barge, was simply obeying the first law of motion. It is subject to no force; all the propelling force is expended on resistance.

The delay in reaching the final value of current after applying a constant E.M.F. to an inductive circuit was strikingly shown by including in the circuit a model "sounder" adjusted to work at a current only just less than the final value which the current will attain. The current was shown to be still appreciably rising after a minute's time in a circuit having but moderate inductance. The conditions which can alter the time constant were also shown by means of the model.

(3) But there was yet another time constant of a circuit—the period of free oscillation. Kelvin showed, in 1853, that the discharge of a condenser through a circuit having self-induction but small resistance consisted of oscillations having a period $2\pi\sqrt{(SL)}$, dying out according to the time constant SR.

$$Q = Q_0 e^{-\frac{t}{SR}} \cos \frac{t}{\sqrt{SL}}$$

Self-induction imparts to the current inertia, or the power of overshooting the mark. Some circuits possess not only self-induction but capacity, and have, therefore, a natural period of free oscillation if the resistance of the circuit only be small enough. When periodic impulses were impressed on such a circuit, their effect was greatly enhanced if their period coincided with that of free oscillation of the circuit itself.

The lecturer showed that the heavy weights of the model, when controlled by springs supplied at either end, could be set in violent oscillation by very small impulses if these were suitably timed. He referred to the fact, observed by Grove, that a Rhumkorff coil works better with than without a condenser in series, on an alternating circuit, but only if the circuit is in tune with the supply frequency. The rebound from the condenser helped the reversal of current when this was the case. The "Ferranti effect" in long cables and all the now well-known effects of resonance in alternating-current circuits were illustrations.

A circuit tuned to the period of an alternating supply which was available (or else to one of its overtones) was shown to oscillate—a telephone included in the circuit giving a clear note when the capacity was properly adjusted; and the harmonics also were picked out and made audible.

Dr. Lodge said it used to be doubted whether electricity was anything like a substance with inertia, like matter had. It was turning out that it had true momentum, so much so that he doubted if any other momentum existed. Instead of explaining electrical phenomena by mechanical devices they would, hereafter, he believed, seek to explain Newton's Laws of Motion by means of electricity. The inertia of

electricity was a reality, and he doubted if there were two kinds of inertia. The inertia of matter they had got accustomed to, the inertia of electricity was a comparatively recent discovery, largely due to the work of J. J. Thomson at Cambridge. He believed matter would turn out to be really an electrical phenomena in itself. By the aid of the vacuum tube, Dr. Lodge showed that electricity in motion had kinetic energy and momentum. In saying previously that self-induction was inseparable from an electric current he only spoke then of an electric current going through wires, but he need not have limited himself to wires. It would be just the same with a convection current. If he took a charged cannon-ball and shot it, they had an electric current. Directly a charged body moved it generated a magnetic field, and that magnetic field continued the motion. It was equivalent to inertia. You could not start the thing without generating the field, and you could not stop it without stopping the field. Electricity had true inertia therefore; whether matter had as well he did not at present assert. They could get electricity isolated and apart in the vacuum tube. In the cathode rays, studied by Crookes and others, you had electrons or charges of electricity which, impinging on a piece of platinum, raised it to a red heat. That meant they had kinetic energy. They generated heat as a cannon-ball striking a target generated heat. A further demonstration of Crookes with the vacuum tube illustrated the momentum of the electrons by operating a small windmill. Thus self-induction, Dr. Lodge concluded, resolved itself into something which he believed would turn out to explain what they had already got so thoroughly accustomed to, viz., simple mechanical inertia.

Mr. Lea.

Mr. H. Lea, in proposing a vote of thanks to Dr. Lodge, said this was the second occasion within twelve months on which he had devoted himself to their interests. The mystery which surrounded the idea of electricity was clearing. It seemed now as if, though they had not acquired a perfect knowledge of what it was, they were on the verge of it.

Mr. Vaudrey.

Mr. J. C. Vaudrey seconded the motion. He said Dr. Lodge had put the mystery of electricity before them in a clearer way than he had ever heard it explained before.

The vote of thanks was carried with acclamation.

Dr. Lodge.

Dr. Lodge, in response, said that Benjamin Franklin was a great deal wiser than had been thought, and that electricity was much more like a fluid, consisting of particles, atoms, much smaller than any atoms of matter. He was therefore unexpectedly near the truth. In this twentieth century they were coming to revert rather to something which, though a great advance on Franklin's view, was a development of it and not a contradiction of it.

CALCUTTA LOCAL SECTION.

THE INSULATION OF CONDUCTORS OF ELECTRICITY IN INDIA.

By K. A. SCOTT-MONCRIEFF, Member.

Paper read at Meeting of Section, March 29, 1901.

I shall endeavour to lay before you in this paper the results of my own experience and of what I have learnt of other people's experience on this all-important question of insulation. I cannot introduce to you any novel theories or discoveries, but I think consideration of this paper may lead to a discussion of many of the minor troubles in this country. I have classified the different conductors under various headings, which, I think, include those used under all ordinary circumstances.

I. *Insulation of Aërial Lines.*—(*a*) Bare Conductors. The Indian Telegraph Department have designed a system of aërial lines which is in every respect a model one. I have made use of it for aërial electric lighting and power circuits in four or five different places. Perhaps I should say that I have copied it. The expression made use of sounds as if I had been switching dynamos on to the main telegraph lines. Such is not the case, although I have been greatly complimented by a lady for the clever idea of sticking the electric lamps on to the telegraph posts.

The insulators I have used are, with one exception, of the Indian Telegraph pattern, the exception being an oil insulator which I have always used without oil. My experience has been gained on the following :—

1. Darjeeling, 2,300 volts alternating	...	3	miles.
„ 230 volts alternating	...	13	„
2. Calcutta, 450 volts continuous	...	27	„
3. Cuttack, 1,300 volts continuous	...	3	„

and other small installations.

1. In Darjeeling the 2,300-volt circuit is carried on oil insulators, and, as I have already said, we have not used oil

with them. The posts carry, in addition to the two main conductors, an earthed head-wire as a protection from lightning. I have no record of any trouble with the insulation of this circuit. It varies considerably owing to the varying humidity of the air, the effect of which is much increased by a network of spider's webs spread between the earthed head-line and the conductors. The following tests show this:—

29th May, 1898, top conductor	...	10,000,000 ohms.
„ bottom conductor	...	Infinity.
4th Aug., 1898, top conductor	...	370,000 ohms.
„ bottom conductor	...	3,000,000 „
31st Dec., 1898, top conductor	...	10,000,000 „
„ bottom conductor	...	Infinity.
31st Dec., 1900, top conductor	...	2,000,000 ohms.
„ bottom conductor	...	3,000,000 „

The head-line was put up between May and August, 1898.

The 230-volt circuits call for no special comment; they are carried on small telegraph-pattern insulators which answer very well.

2. There are two special features about our lines in Calcutta, namely, the weight of the heavy line of No. 0 copper wire, weighing practically one pound per yard and carried in 150-feet spans on large telegraph-pattern insulators, and the pressure of the lines to earth, namely, 225 volts. We have no trouble with the heavy wires. As to the difference of potential to earth, I do not think that trees touching the line even during heavy rain sustain or cause any damage. I have heard of crows, kites, and flying foxes being cremated, through making contact between our outer wires; I have never seen it happen, nor have I been shown any charred remains.

3. A 1,300-volt arc circuit at Cuttack gave every satisfaction; it was insulated on ordinary telegraph-pattern insulators.

II. *Continuously insulated Aërial Lines.*—The only insulation that I have used for this class of work is vulcanised indiarubber. The high-tension lines are carried on steel suspending-wires by means of tags at short intervals. I find

that raw-hide tags only last about two years in Calcutta, and have accordingly used some made of porcelain, which have given no trouble.

I have laid upon the table two samples of cable :—

A—has been up in Calcutta from June, 1895, to February, 1901, carrying 1,300 volts continuous current.

B—has been up in Darjeeling from November, 1897, to February, 1901, carrying 2,300 volts alternating current.

Both of these cables are made by Henley's Telegraph Works Company, they are insulated to Board of Trade requirements as to thickness of dielectric and to some 3,000 megohms per mile.

The excellent condition that they are in surprises me when I think of the burning sun and pouring rain to which they have been exposed. Sample B has also been at times coated with ice.

III. *The Insulation of Underground Conductors.*—The choice of a suitable system of underground conductors for India is a fit subject for a separate paper confined entirely to the special consideration of that particular question.

None of us in India can claim to have much experience of such mains laid in this country, and even the Telegraph Department has tried very few underground cables, *except those that are under water.* I am informed that such cables give trouble only at the shore ends, that is in the underground portion, and most trouble of all where the line emerges from the ground and goes overhead.

There was, however, an underground telegraph line half the way from Diamond Harbour to Calcutta. It was a bare iron wire laid in an earthenware trough and run in with a compound of resin and sand. This line was laid in 1851, and subsequently abandoned. The insulation was defective, and it also suffered a good deal of damage from subsidence of the soil in which it was laid and from the roots of trees forcing their way through it.

For electric lighting purposes vulcanised indiarubber as an insulator has been tried underground. For cables drawn into iron pipes it did not prove a success when used a few years ago in Calcutta. The circuit I refer to was for arc-lighting working at 1,300 volts. The cable used was of

the best class, but I am inclined to think that high insulation cables are not the most satisfactory for this climate.

High insulation resistance is, I believe, obtained by wrapping pure rubber on the cable, this in turn is wrapped with vulcanising rubber, and then tape, and the whole is vulcanised together; but the pure rubber does not become thoroughly cured, and has therefore not got the lasting properties of vulcanised rubber.

I supplied an indiarubber-covered cable for a somewhat similar circuit about six years ago, and it is, so far as I know, doing well. It is in use in the Punjab, and is drawn into 3-inch earthenware drain-pipes; the cable is insulated to Board of Trade requirements as to thickness of insulation, and is very heavily braided.

In 1888 a pair of cables was laid between two mills—the Dunbar Cotton Mills at Shamnagar. The cables were insulated with pure rubber lapped and braided; they were laid in ordinary two-groove teak casing, which was run in with pitch before the cover was screwed down. I examined some portions of the cable in 1896, and found that white ants had just begun to attack it. The essential oil of the teak had through time dried up, and so the wood had ceased to be obnoxious to the white ant. This cable was condemned the following year. Its length was 120 yards, and it worked at a pressure of 100 volts.

At the Eden gardens in Calcutta the installation of Jablochkoff candles has been in use since 1880, using underground mains, consisting of cables insulated with pure rubber lapped and braided, laid in teak casing run in with bitumen. The voltage of the circuits is about 35 alternating.

It was first proposed in Calcutta that we should use bare conductors strained up in a culvert; but in consideration of the heavy rainfall and the difficulty that would be met with in draining such a culvert, this system was abandoned.

We had to find a system of mains that would not deteriorate when exposed to the specially trying conditions which obtain in Calcutta. These are :—

1st.—The excessive damp.

2nd.—The heat.

3rd.—The deleterious action of the soil upon all lead pipes, &c.

4th.—The want of skilled labour.

We finally selected Callenders solid system, in which the cables insulated with vulcanised bitumen are laid upon wooden bridges in a trough, the whole run in with pure bitumen.

A question then arose as to what the trough was to be made of. We finally selected pinkado, a wood growing in Burma, of which we received most satisfactory accounts; but when we tried to buy the timber we were unable to obtain it. Inquiries were made as to earthenware troughing made locally, but we could not get what we wanted, and ultimately had to use cast-iron troughing.

The great drawback attending the use of iron troughing is that, when a fault develops it rapidly becomes a real short circuit, so much so that in some cases several feet of cable have entirely disappeared through this cause.

I have experienced a good deal of trouble from faults developing at the bridge-pieces. These are spaced some 18 inches apart, and it was noticed that in every case where these faults developed it was at a bridge-piece which came at the junction of two troughs of troughing. This was attributed to moisture getting in at the joint between the iron troughs. The number of such faults has not exceeded twenty, and there are about 10,000 joints, all exposed to moisture. I am therefore of opinion that the cause of the fault must be sought elsewhere, and I explain it as follows: any change of the level in the main owing to settling or subsidence of the ground upon which it is laid can only be met by a movement at the joints in the troughing. Now if the joint gives, the bitumen must give also, and it would, under ordinary circumstances, bend; but the bridge-piece extending over about half the sectional area of the bitumen weakens it, and I think that it cracks at this weak point instead of bending gradually. Our only other source of trouble has been where the bitumen was poured into the troughs when boiling. The surface rapidly cooled and prevented the steam escaping thereby, making a spongy casting.

We have not been at work long enough in Calcutta to test this system thoroughly, but we have had the advantage, from a testing point of view, of very severe floods. I therefore hope that all the weak points have now been brought to light.

Callenders solid system is also, I believe, in use in Madras, and gives every satisfaction there.

In Colombo I believe the mains laid underground are on the British Insulated Wire Company's System, but I have no information as to how they have answered their purpose.

IV. *Insulation of House Circuits.*—The testing of insulation resistance in Bengal does not afford us such definite information as can be obtained from it in Europe with regard to the way in which the installation has been carried out. This is chiefly because, owing to the humidity of the air, surface leakage on switches, cut-outs, and other fittings, is very much increased, and it is under ordinary circumstances impossible to say how much leakage is due to that cause and how much to defective work. Another difficulty is that in dry weather the walls of a Calcutta house are in themselves very good insulators, but in damp weather they may be described as excellent conductors.

The only damage that I have found to result from surface leakage is where (and this is not a common occurrence) the metal parts of switches, etc., have been destroyed by electrolysis. I may also mention that in those cut-outs which have a combustion chamber, into which the fuse-wire is taken though pin-holes in the porcelain, I have had many complaints of the fuse-wire being eaten through at the point of entry. I cannot say whether this corrosion is due to electrolysis or to some chemical action from the glaze of the porcelain.

Some trouble has been experienced through insufficient insulation of switch handles. One cannot be surprised at this being found on the ordinary tumbler-switch, but I was astonished to hear that a nasty shock could be obtained from the ebonite handle of a main switch on a 230-volt alternating circuit.

I have seen a good many wiring installations lately, and I am sure that our work in India is as good as the average in Great Britain, and much better than the average in France and Switzerland. During the last two years the equivalent of some 30,000 8-c.p. lamps has been wired for our supply in Calcutta, and the equivalent of more than 30,000 8-c.p. lamps for isolated plant has been installed by Calcutta firms. This work has been done by natives trained and supervised by not more than a dozen European experts.

The wiring in the various mills around Calcutta was largely carried out with conductors insulated with a little, very little, pure rubber, protected by cotton covering and tape or braid. I refer particularly to these which were wired about ten years ago, but I am sorry to say that similar work has been done more recently. However, even with such low-class work little or no trouble has occurred.

In Calcutta house-wiring some cables have failed owing to really bad vulcanised rubber being used, but in other cases good wire has not proved satisfactory. I know one batch of wire which was used for mill-wiring, for house-wiring, and for wiring a troop-ship that went to China. In the mills and in the trooper all has gone well, but in the Calcutta houses faults have occurred. I have brought with me to-night a sample of such a faulty wire.

The deterioration cannot be due to heat alone, as the same insulation has stood well when working in a troop-ship in the tropics. It may be due to some deleterious action of the teak casing, but in the trooper and in the mills teak casing is used. I do not think it is due to damp alone, because I have used similar wire in street posts in Darjeeling, and although no special precautions were taken to keep them dry, they have lasted in a most satisfactory manner. In Calcutta also where our aërial lines are led into the houses, the cable in the iron tubular bracket are exposed to a good deal of moisture. I have also used this class of wire for open work lying along the plaster walls, and have had no cause of complaint.

I feel sure that the failure of these wires is because they are exposed to damp and heat and not ventilated. The wires are shut up in a casing, and the whole becomes wet and rots. I do not think that any insulation will stand under these circumstances.

Having such trouble to face when cased wires are used, one naturally turns to other systems. I have used interior conduits made of 1-inch compo pipe, and such work has stood well for the last six years; I have not, however, done enough of it to say whether it can be relied on in all cases. In this system it is important, I think, to use good large pipes, so that the insulation may be well ventilated.

Ordinary lead-covered wires have been used in many parts of India, especially in Colombo. I know that they

have given trouble in the North-West and in Calcutta. I have not heard whether they are satisfactory in Ceylon. I have used them for wiring river steamers and have had no trouble, but the cause of trouble is not to be met with on board ship, as the damage is done by salts in the soil and in the plaster of the house walls.

Lead water-pipes are not satisfactory in Calcutta soil, but compo gas-pipes are freely used in Calcutta houses, and I do not think any marked deterioration takes place in them.

V. *Dynamos and Motors.*—During the past eight years in India I have had to do with over a hundred dynamos and over a thousand motors. I do not think that any of these machines were materially altered in their design to render them particularly suitable for working in this part of the world. I have used Gramme dynamos built in 1877, and I know one that is working to-day, and multipolar dynamos built in 1900. I have only met with six faulty armatures amongst the dynamos and eight amongst the motors; one faulty field winding amongst the dynamos and 40 amongst the motors.

Of the six faulty armatures, three appeared to be damaged by climatic conditions. They were Brush machines sent out in 1884, and in 1894 I examined some of the coils to find that the cotton insulation had turned brown and perished very much, in the way that the leaves of an old book go in this climate. The other three faulty armatures had not broken down from special climatic or local causes.

The heavy list of casualties amongst motors is almost entirely confined to ceiling fans. I do not blame our local conditions for this; I think the chief reason of these failures is that every one cannot make small 225-volt motors; the winding of such machines is a delicate operation and can only be learnt in time, so when Calcutta ordered 3,000 motors the makers were unable to find skilled hands to make them. Another factor in the case is that the strain of 225 volts to earth is very heavy for the insulating material, which is of necessity very thin on the fine wires required for winding the motors. I may also point out that many, in fact nearly all, of these motors have little or no attention during the eight months that they are continually in use.

One of my own fans ran for three months without being turned off at all.

I have much pleasure in stating that two alternators which were buried in broken rock, sand and water, during the cyclone of 1899, in Darjeeling, were dug out, washed and started up, and are nightly working at 2,300 volts.

VI. *Instruments.*—With regard to the insulation of conductors on instruments I can only quote one case in which I have had trouble, and that is, in a certain class of meter which was tried for measuring the supply to some Calcutta houses. These were wattmeters, of which the shunt coils were wound on porcelain bobbins. Many of these coils failed; I think that the surface leakage was sufficient to eat away the very fine wire used for these coils, and in that way break the circuit through them.

In conclusion, I submit that the following deductions may be arrived at from the foregoing notes:—

I. The system of insulation for aërial conductors used by the Government of India, Telegraph Department, is suitable for conductors weighing up to at least one pound per yard run, and for pressures up to at least 2,300 volts.

II. Vulcanised indiarubber is a suitable covering for aërial lines.

III. We have still to find out by experience the most suitable system of insulating underground conductors.

IV. House-wiring where there is any chance of damp penetrating to the cables should not be done in wood casing; therefore wood casing should not be used in Calcutta.

V. The climate of India is by no means a bad one—for dynamos and motors.

VI. In fine wire coils surface leakage must be carefully guarded against.

Mr. C. T. Williams (*communicated*): With regard to underground conductors in use in the Indian Telegraph Department, these are mostly of the lead-sheathed type, the insulation being hemp impregnated with a semi-fluid. It has been found that the chief cause of failure is electrolytic action on the sheathing when in the vicinity of electric tramways. A great deal of trouble was experienced in Madras some two or three years ago, and it was possible to trace the current in the lead sheath at Mr. Williams.

Mr. Williams.

points two miles from the tramway. I believe that the rebonding of the tramway rails has improved matters at Madras. The effect on the lead sheath was to cause it to disappear altogether for the length of a yard in some places, while in others it was perforated with small holes. Of course in such cables the smallest hole means a leakage of the insulating fluid, and it is found that when this takes place the hemp insulation dries and loses its insulating properties. It is possible that such cables would do well if buried in bitumen.

Pyngado (or ironwood) has been mentioned by the author of the paper under discussion as a possible material for cable troughs. From what I know of the wood, it ought to last well in the Calcutta soil, which is always more or less damp. I have dug up in Burmah old telegraph masts, and have found that where they had been constantly in wet ground—namely, at the base—the wood was in perfect condition. There would be no great difficulty in making troughs with this wood, and it ought not to be difficult to procure from either of the ports on the Arakan coast. All the telegraph posts on the west coast of Burmah (Arakan) are of pyngado.

As regards interior wiring, the evidence is apparently strong against wooden casing, and this comes to me, at any rate, as news. In the Telegraph Department it has been the custom for years to run "Hoopers Core," which is used for office connections, and which has a high insulation to maintain, in grooved boards, or casing, without covers, however. The grooves are made so that the wires will fit tightly, and when the work is carefully done and all corners are rounded off, the effect is not inartistic. So far as I know the under side of the wire remains in as good condition as the side exposed to the air, although it is pretty certain that the tightness of the fit keeps air away from it. An occasional wooden cleat precludes the possibility of the wires leaving the grooves should they by any chance become loose. Wiring done in this way remains good for many years. Something in the way of casing appears to be necessary, if only on the score of neatness, unless the "concentric" system of wiring is adopted. This has, I believe, been found satisfactory in the lighting wiring at the Madras Tramways central station. In wiring for motor fans, and sometimes for lamps, in Calcutta, I have noticed that where casing is not used the conductors are run along the walls and bound to small insulators at every few yards. There is no doubt that if this kind of work is well done it may be quite efficient. It is cheap, and lends itself to constant inspection. Unfortunately it is not always carefully done, and when one sees wires tied to insulators with string, and the space between one insulator and the next so great that the wires nearly touch each other, one cannot help thinking that it has a makeshift appearance. If the wires were supported on insulators at every yard at least, and were properly tightened, the effect need not be an eyesore, especially if, in addition, the colour of the wire covering matched the wall. I see no reason why, within certain limits, this could not be done. The difficulty is no doubt the want of skilled labour, and it can hardly be expected that the necessary supervision can be always given when a number of works are in progress, but something certainly requires to be done to improve the existing wiring in many cases.

The author has not touched on the point of connecting one floor with another. The most efficient way appears to be to use metallic piping and to continue this for at least eighteen inches up the wall, after passing through from the floor below. This precludes any chance of water used for washing down the floor being splashed over into the tube. If the conductors fit easily, this would not be a serious matter, as any water would run right through, but this is not always the case, and in India it is well to "make assurance doubly sure." Mr. Williams.

As to the rotting of the insulation on dynamo and motor coils, the same thing is noticed in very old telegraph instrument coils when unwound after long service in India.

Mr. Scott-Moncrieff's paper is a valuable one, and it is to be hoped that the facts brought to light will lead to some really efficient system of wiring being adopted which will withstand the very trying conditions of the Indian climate.

Mr. J. WILLIAMSON: I should like to know if the reason for using oil insulators without oil was that oil is not considered necessary, or on account of the difficulty in obtaining a suitable oil. I had a line of about three miles length in Africa in a latitude rather higher than that of Calcutta, and found that the ordinary resin oil solidified during the first hot weather. I had the insulators cleaned, and they proved quite satisfactory for 1,400 volts. Mr. Williamson

The author states that he has had no trouble with the heavy conductors carried overhead. Has any trouble been experienced with the lighter wires during heavy gales?

With regard to the selection of a system of underground conductors for electric light and power purposes, I think perhaps the most suitable insulation would be oil, the conductors being covered with a fibrous braiding or lapping and contained in iron or earthenware tubes, such as the Brooke's system. I do not know if any of these mains have been laid in India, but certainly the objections which apply to most other systems would be absent. The chief objection would be the comparatively high initial cost.

Nothing has been said in the paper about the protection of insulation against damage by lightning, and it would be interesting to a comparatively new-comer like myself to hear what precautions have been found necessary and ample to guard against this serious danger. For the forty miles of trolley wire which are to be erected for the tramways here, we are providing thirty-one lightning arresters and choke coils in the switch boxes between the trolley wire and cables. Arresters and choke coils will also be provided at the power-house and on each motor car for the protection of the insulation of the generators, and the motors, wiring and lighting circuits, respectively.

With regard to the deterioration of the insulation of the Brush armatures, if the cores were of the old cast-iron type, as is probable with machines built before 1884, the heating due to currents in the core would cause this. I have found the same effect in England.

I believe that the disappearance of lead sheathing of conductors mentioned in Mr. Williams' contribution has also been noticed in Calcutta, where at present there is no electric traction, and is due to the presence of some salts in the soil.

Mr. A. H. Simpson.

Mr. A. H. SIMPSON: In one or two instances in which wire of a 2,000 megohm grade has been installed in dwelling houses, and has been laid in ordinary two-groove teakwood casing, the wires have fired for a length of about a foot, and this without any apparent reason, and after being installed only about three months. The wire when installed was new stock and in first rate condition, the casing was apparently dry, and no nails or screws had been fixed at the particular spots. This may be due, as Mr. Scott-Moncrieff remarks, to the action of something in the teak casing used. I may as well remark that these wires were not carrying current at a greater capacity than about 200 amperes to the square inch.

There is no doubt in my mind that an installation in which the wires are laid side by side on porcelain cleats will give much better results as regards life and test than one in which they are laid in ordinary teakwood casing such as is commonly used in India, and I also am of the opinion that the humidity of the atmosphere would cause the braiding to rot very quickly, and that the rubber would perish, when enclosed in casing.

There is also to be considered whether any foreign substance introduced into the rubber contributes to the rapid perishing of the latter, and also if such additions account for the vulcanised rubber in some batches of wire turning into a white paste of the consistency of very thick cream, the braiding not having deteriorated in any way, or whether the effect is due merely to bad vulcanising.

With regard to wiring on porcelain cleats, this system should be carried out in a thorough manner, not merely using cleats and then passing the wires through the walls in "compo." pipes and finishing off the wires at the switches and ceiling roses in teakwood patrasses, as is usually the case, but the porcelain switch, ceiling rose, and distributing board bases should also be so made that the wires may be drawn into holes in the sides, so that the ends of the wires may be insulated from the walls. The only objection, I think, that can be made to this system is that it does not lend itself to a decorative effect as well as wood casing does when used in dwelling houses.

Most of the corrosion which I have noticed in switches is due to moisture charged with salts from the walls having collected in the casings and gravitated down the switch casings, and having no other outlet when the casings are painted, has passed along the wires through the holes in the porcelain bases and on to the terminals of the switches; this, therefore, raises another objection to the employment of wood casings. With regard to "compo." pipe, although this has proved satisfactory generally, I have had taken out of walls pieces which have been full of small holes, evidently caused by the chemicals contained in the walls.

One reason for the breakdown of so many ceiling fans is the fact that the motors are made as small as possible for the sake of appearance, so that only a minimum amount of insulation can be used, and also the fact that, these fans being made out of India, sufficient regard is not paid in the insulation to allowing for the dissipation of the heat generated during the long hours they have to run.

There is little or no leak to earth on the fans provided that they are properly suspended by the porcelain insulator fixed on the rod of most of them. Mr. A. H. Simpson.

Mr. W. THOM: I. *Insulation of Aërial Lines* (*a*).—Mr. Scott-Moncrieff mentions that in one case he used an oil insulator without oil. I should say that the insulation would in this case become very low by the time that a collection of dust has filled the oil recess. If the author had given us some idea of the length of the line under reference we should have been able to judge of the quality of the insulator; as it is, we are simply given the test of a line, which may have been a mile or even six in length. Mr. Thom.

(*b*) Although trees may or may not cause damage, it would appear to me to be a very unsatisfactory condition of things to have them touching, say a 2,300-volt circuit, the wires (if originally insulated) having become bare through continual rubbing. Taking into account all sorts of risks, it is not impossible that such a line might be the cause of hurt, or even of death, on a leaky supply, particularly if an earthed return is in the near vicinity, and the Company might then be liable to a considerable amount. The expression made use of by the author regarding the difference of potential to earth has, perhaps, reference only to damage to machinery, although, however, he mentions that the trees may be damaged.

II. *Continuously Insulated Aërial Wire.*—Does the author imply that vulcanised india-rubber without any other is suitable covering for aërial wires? It has been found in some cases, when thus used, to perish, crack, and lose much of its insulating power.

III. *The Insulation of Underground Cables.*—Reference is made to the vulcanising of rubber-insulated cables. I do not know that any maker intends that the pure rubber coating should be cured entirely to the core, because of the effect vulcanised rubber has on the copper even after being tinned. Callenders' solid system is not in use in Madras, but their lead-covered and steel-armoured system is and has given satisfaction. I think we may take it that the longest lived cable in England will prove under certain conditions to be the best for India.

IV. *Insulation of House Circuits.*—I should say that a standard could be arrived at with regard to house circuits. It would appear that a lower insulation resistance is to be tolerated in India than in England, although the author proves that a higher one is necessary to give good results for any length of time. No doubt India is a place for the concentric system of wiring.

V. *Instruments.*—Perhaps if ebonite were used instead of the porcelain bobbins, like failures might be prevented.

Mr. P. BRUHL: I cannot agree with Mr. Scott-Moncrieff in his condemnation of wooden casing, except when fixed on very damp walls or ceilings. The wooden casing should, however, always receive at least two coats of varnish inside and out. I have had good results with casing impregnated with a hot solution of paraffin in boiled linseed oil and then varnished. I have also used casing well painted with silicate paint. It is often a good plan to screw the casing to a plug projecting Mr. Bruhl.

Mr. Bruhl. $\frac{1}{8}$ or $\frac{1}{4}$ inch. In houses as they are built on the plains of India there is little risk of fire arising from the use of wooden casing. The mains at Sibpur Engineering College are lead-sheathed cables laid into the bare ground about five years ago; they have not apparently suffered, but the soil is light and sandy and not rich in humic acids. Generally speaking, however, I cannot recommend this procedure.

Mr. Burne. Mr. O. BURNE: We have had in the Telegraph Department some considerable experience, for over thirty years, of gutta-percha and india-rubber cables under water in the big rivers and underground, in their shore ends, which are often more than a mile in length on each side. Our experience has been that both will last in good condition almost indefinitely under water or damp ground; but that in dry ground, or ground which is alternately wet and dry, the insulation will fall from many thousands of megohms to a fraction of a megohm per mile in from six months to two years. For the last seven years we have used lead-sheathed gutta-percha for the shore ends of our gutta-percha and india-rubber cables with excellent results. Both materials protected from oxidization by lead-sheathing seem to last as well as they do under water, even where they are quite dry and very hot, as they are at the ends in our little iron cable-houses, in which the temperature often rises to 130° F. The life of lead sheathing seems to depend very much upon the soil it is buried in. In Bow Bazaar, a few years ago, we dug up some lead-sheathed india-rubber cable which had been buried in or before the Mutiny. Both lead and india-rubber were quite perfect. Against this may be set a case where some lead-sheathed Fowler-Waring cables, buried some thirty miles from Calcutta down the river, in a rotten vegetable earth, were eaten through in less than six months. In these the lead was unprotected, except for a layer of tape. Quite close to them was a lead-sheathed india-rubber cable with three servings of hemp and iron-wire armour, which had been down ten years, and yet the lead was quite perfect. In the same soil and place we have now had some lead-sheathed india-rubber cables with a thick serving of tanned hemp, which have now lasted, I think, three years at least, without any signs of the lead being attacked.

Mr. M. G. Simpson. Mr. M. G. SIMPSON: It is difficult to imagine a more apt subject than the one chosen by our Vice-Chairman for the first paper of our Local Section, as it is undoubtedly the most important point in which our conditions differ from those prevailing in Europe and America. First I wish to give a word of warning on the subject of insulation of aërial lines, and that is that we have found sulphur-cemented insulators do not answer in India. We have found many cracked vertically through. It is probable that, from the excessive heat, the steel stalks expand, and the cement is too rigid to give at all, with the result that the porcelain cracks. The crack would be almost invisible, certainly so from the ground, but when the wire was unbound the insulator would tumble to pieces. We now use Portland cement for fastening the stalks, and this has been found to answer well. Screwed stalks also answer well, and are in many ways convenient to us, as when a cup breaks we can easily fix another at any point on the line.

There are certain sections of line where we have found our

ordinary insulators, good as they are, not good enough, and on these we use oil insulators with oil which have been found a decided advantage. I may, perhaps, mention that the worst conditions we meet with are in those districts near the sea where a strong wind covers the insulators with salt-laden sand, which becomes saturated with moisture when a fog supervenes at night. As soon as the rains come and wash the insulators, matters at once improve. Inside our offices we have not taken any very special precautions to maintain good insulation, nor was this a matter of very great importance so long as we used primary batteries incapable of giving even one ampere, but with the introduction of accumulators we shall be obliged to maintain a high insulation, and shall welcome the experience that members of this section will be able to give us. Mr. M. G. Simpson.

Mention has been made of flying foxes. I have measured the resistance of these when dead. They vary greatly, of course, but show in the nature of two to three thousand ohms from claws to teeth, and would therefore be difficult to cremate. However, they are apparently easily electrocuted when they get across from one wire to another. They are very difficult to localise, as they charge up like badly constructed accumulators; and it is impossible to say whether one's observations are controlled by the testing battery as one hopes, or by the flying fox as one fears. The flying fox is not a very big animal, so that if wires, in localities where they give trouble, are placed 18 inches apart, there is little risk of their doing much damage.

In the laboratory in a climate such as we enjoy in Calcutta, surface leakage at times leads to surprising results, and has to be very carefully guarded against.

Mr. J. W. Meares: With regard to the high tension aërial lines at Darjeeling I have one or two remarks to offer. The author mentions the effect of the network of spider's webs in reducing the insulation resistance, but I do not think this effect is so great as he supposes. On many occasions when the line was covered with webs all through the jungle near the power-house, and the webs appeared saturated with dew, the charging of the line had no effect whatever in the way of dispersing this dew. Evidently, therefore, as a practical factor it is negligible, presumably because the webs are high insulators and the deposited dew is in the form of beads entirely isolated from one another. Again, as regards the method of insulating, this is done on the telegraph plan across the greater part of the distance and by means of insulated wire in the station, but where the two parts join there is some work of a chequered nature, insulated wire over road crossings and bare wire between them. In such a case I think it would be worth while to try carrying the bare wire over the crossings on porcelain suspenders carried by a stranded steel bearer wire, which would render falling next to impossible unless pole and all fell. I am aware that this does not fulfil the regulations to the letter, but the method actually adopted does not fulfil the real intention of the rule, and is a more or less absurd form of construction. Mr. Meares.

As regards electrocution on bare wire circuits, I have seen several instances of this on birds in Darjeeling and one on a flying fox in

Mr. Meares. Calcutta. I do not know if the crows that recently built a nest of iron turnings on the "outers" in Calcutta shared the same fate!

As to underground mains, there is one advantage in iron troughing that was not mentioned, namely, the protection afforded by it to other neighbouring metallic pipes, etc. As to internal wiring, I agree with the author that the *average* work in India is as good as that in England, but a good deal of the work is much worse than anything I saw in 1894–95, when inspecting houses for connection to the Hove Electric Lighting Company's mains, chiefly owing to scanty and untrained supervision. I may say also that within the last month I was surprised to come across some unvulcanised sub-mains in use in a mill near Calcutta in an otherwise fairly satisfactory installation. Corrosion of switch and fuse terminals I frequently see, and I am afraid an alteration of the climate is the only cure. As to the general question of house wiring, it is to my mind quite an open question whether unencased wires will not eventually prove the best and most lasting, though with their use a very careful system of distribution and sub-division is necessary, as well as absence of joints. When Government House, Calcutta, was wired, I specified that joints were to be vulcanised, but there are of course grave difficulties in carrying this out in house wiring, and it adds greatly to the expense. As an alternative I suggested the use of ordinary bow cut-outs as "connectors," using one terminal only, and of course no fuse, and I have found the result most satisfactory so far. In another installation under my charge, joints have been made inside a bow cut-out (from which both terminals have been removed), and the joint remains uninsulated, except by air, inside the cover, but not touching. So far this also has proved satisfactory, but it does not offer the same facilities as the former method for dividing up circuits to find a fault. For passing through walls I am strongly in favour of the Doulton pipes now obtainable in Calcutta.

Mr. Scott-Moncrieff. Mr. Scott-Moncrieff (*in reply*): With regard to oil insulators I may say that the oil was never used, so I do not know how it stands the Indian climate. I have been told by friends in the telegraph department that the oil chamber gets filled with insects. If Mr. Thom refers again to the paper he will see that the line is three miles in length. It is carried for the most part across tea-gardens, and there is practically no dust to get into the insulators.

I believe that the telegraph department requires a higher insulation per insulator than is wanted for electricity supply work. In the latter case we have only to guard against damage to the conductors at the points where leakage takes place, but in the former case we have to conduct small currents from one end of India to the other, and special care is required to prevent their being lost *en route.*

Mr. Williamson raises the question of lightning. My experience is as follows:—In Calcutta we have cow-horn arresters every quarter of a mile and, in addition, at every house service. During thunderstorms we get occasionally a flash at the brushes of the dynamos in use. We have had no damage done that can be traced to lightning.

I may point out that our lines in Calcutta are practically level, and that when travelling in Switzerland I found that experience there goes

Mr. Scott-Moncrieff.

to show that damage by lightning generally occurs where there is change in the level of the line. This is borne out by our experience in Darjeeling, where the high-tension line rises 3,500 feet, whereas the low-tension circuits have a maximum variation of about 400 feet. On the three miles of high-tension line we have during a thunderstorm repeated discharges, while on the thirteen miles of low-tension we have no record of any such disturbance.

The high-tension line was first protected by Wurtz arresters every quarter of a mile. We then added groups of "cow-horn" arresters at each end of the line; each group consists of 50 pairs, and we find that they act freely and prevent the charge from reaching the alternators, but do not entirely safeguard the transformers; we have therefore added small choke coils, and so far no further damage has occurred. The total damage done amounts to three transformers being burnt out.

I quite agree with Mr. Thom that 2,300-volt lines ought not to touch trees; I have no experience of their having done so. I think he misunderstands what I have said about house circuits. The dangerous leakage is that from the cables and wires, and in damp weather it is difficult to dissociate this from surface leakage, which is as a rule harmless.

DUBLIN LOCAL SECTION.

NOTE ON A HUMMING TELEPHONE.

By F. GILL, Member.

(*Paper read at Meeting of Section, April* 18, 1901.)

My excuse, if one be needed, for bringing this matter before you must be that our late revered Chairman, Professor FitzGerald, was interested in the matter when it was brought under his notice, and further that, so far as I have been able to ascertain, the behaviour of the humming telephone, as I hope to show it, is new and has not been published hitherto. This note is merely a record of a few experiments carried out at odd times since the effect was first noticed by me two years ago.

The ordinary humming telephone is, of course, well known, and was first noticed by A. S. Hibbard, of the United States, in 1890.[1] We have Hall effect and Ferranti effect, why not Hibbard effect?

In Hibbard's experiment a telephone is held against or near to the diaphragm of the microphone, and a hum or whistle is set up and continues.

A rough explanation of the experiment is that in the first place some slight noise is taken up by the microphone, and the sound is, in the usual way, given out by the telephone; but, because the latter is near the microphone, the sound waves set up by the telephone affect the microphone, which in turn again acts upon the telephone, and thus the reaction is maintained.

The connections in this case are those ordinarily used in telephony, where the microphone is in series with the battery and with the primary of the induction coil; the telephone in series with the secondary of the induction coil is short-circuited.

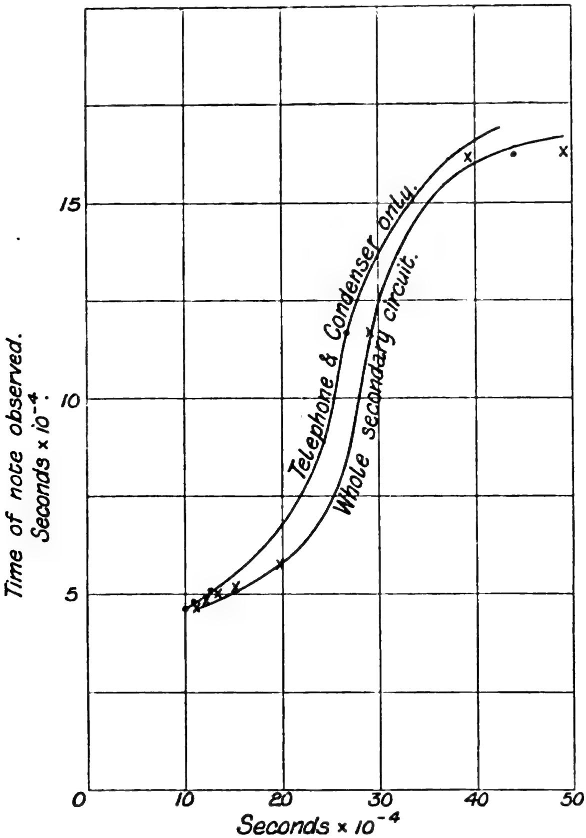
The feature which I believe to be new is that, if the wires leading to the telephone be reversed while the instrument is humming the note at once changes in a striking degree, and if the hum is stopped it will recommence again, high or low, according to the side the reversing switch is set. It is also to be noted that the high note starts more easily and is altogether more vigorous than the low note. Of course, reversing the current in the primary circuit also produces the same change in pitch, and if the primary and secondary circuits be each reversed simultaneously no change is observed.

Returning to the ordinary humming, the exact conditions which determine the note given by the telephone appear to be most complex, apparently every portion of the circuit and instruments has a share in

[1] *Electrical World* of New York, September 19, 1890.

determining what the note shall be; but the note can most easily be varied in one of the following ways:—

By altering the conditions of the circuit by adding resistance, capacity, or self-induction. Speaking generally, if a non-inductive resistance be introduced into the secondary circuit the pitch of the note goes up, and at the same time the sound becomes weaker by attenuation.



$$T = \frac{2\pi}{\sqrt{\frac{1}{CL} - \frac{R^2}{4L}}}$$

FIG. 1.

In this experiment, if made with double-wound resistance coils, I think there is a good deal of condenser effect across the winding of the coils.

Adding capacity across the telephone lowers the note. It is quite easy to compare roughly different capacities in this manner; for instance, in trying this, three condensers of ·96, 1·1, and 1·3 microfarads respectively were at once picked out in their proper order, the condenser with the lowest capacity giving the highest note. The

curve shown in Fig. 1 gives the result of adding capacity. The time of the note observed is plotted with the period of the whole circuit neglecting the primary circuit, and is also separately plotted with the period of the telephone and condenser only. The curve is given as a result obtained in a few trials. The figures are shown in the table:—

Effect of Capacity Added across Telephone.

Resistance	whole circuit	145ω
„	telephone	120ω
L.	whole circuit	·166
„	telephone	·13

Capacity.	Time of Note observed.	Time of Whole Circuit.	Time of Telephone and Condenser.
·2 mfd.	4·8 $\times 10^{-4}$	11·25 $\times 10^{-4}$	10·07 $\times 10^{-4}$
·23 „	4·9 „	12·08 „	10·86 „
·29 „	5·04 „	13·55 „	12·21 „
·37 „	5·15 „	15·3 „	13·79 „
·56 „	5·68 „	19·82 „	16·97 „
1·33 „	11·7 „	29·09 „	26·13 „
2·41 „	16·1 „	39·27 „	37·41 „
3·74 „	16·2 „	49·1 „	43·9 „

Adding self-induction to the circuit lowers the pitch of the note. Conversely, adding resistance in parallel (leakage) lowers the note, and self-induction in leak or capacity in series raises the pitch.

The following is an interesting case. The secondary circuit is open as in Fig. 2 (*a*), and is connected to a coil without iron and having two

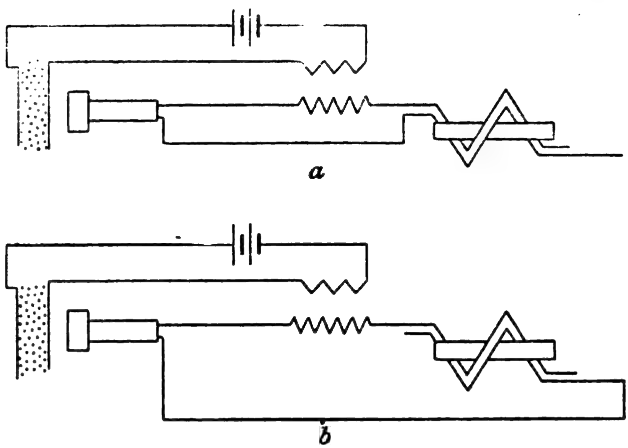


Fig. 2.

wires wound thereon side by side, each having about 1,400 turns. The capacity between the two wires is ·06 mfd., and the self-induction of

each coil is about ·1. If the connections are made to the two wires entering at, say, the left-hand end, the note is higher than if connected to opposite ends as in (*b*); in one case the difference was from 2,280 to 2,120 vibrations per second. This is due to an alteration in the induction, which is less when the wires enter at the same end as in (*a*), than when they enter at opposite ends as in (*b*), and consequently the note given in (*b*) is lower.

The note may also be varied by altering the current in the microphone. Increase of current causes the note to become very slightly lower in pitch.

The strength of the field may be varied and alter the note. In this experiment the arrangement is as in Fig. 3.

As usual the primary and secondary circuits are used, but a condenser is in series with the telephone. Across the telephone itself is a shunt circuit of a battery and a self-induction. This allows the strength of the magnetic field of the telephone to be varied while in use. The self-induction in the shunt circuit prevents too much of the humming current being shunted out of the telephone. If the current from the battery marked A is applied so as to strengthen the magnets of the telephone, the note goes up in pitch and becomes louder, while if the current is sent in the reverse direction, almost at once the hum is stopped. In the telephone tried (an Ader), the current, strengthening the field, was varied from 8 to 112 milliamperes and showed a rising note; when, however, 17 milliamperes were sent through the telephone in the direction to weaken the magnets, the hum ceased. If a current be used to strengthen the field the humming may generally be the more readily set up.

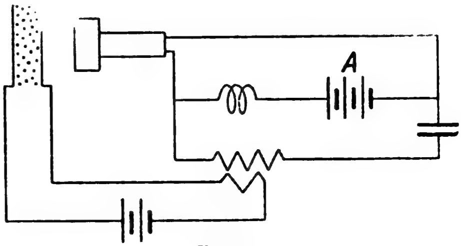


FIG. 3.

Variation of the distance between the two diaphragms gives an alteration in the note. On the high note side, increased distance gives a higher pitch. On the low note side, as the distance between the two diaphragms is increased the pitch rises until a sudden change occurs in the character of the note. If a tube be used to confine the air waves the difference in the note at different distances is striking.

Pressure inwards on the telephone diaphragm causes the pitch of the note to rise.

The following are briefly mentioned as points which have been observed. In some cases the hum will not commence until the current in the microphone has fallen to a certain value. The current in the microphone in a number of cases was about ·18 amperes, being about 28 per cent. less when humming (low note) than when at rest (·25 ampere), and 40 per cent. less (·15 ampere) when giving the high note with no external circuit.

I am indebted to Mr. W. W. Cook for the following interesting case. In a common battery circuit as shown, Fig. 4, and using a hand microtelephone, it is possible to set up the hum, although in this case the diaphragms are not opposite to each other, and are distant 8½

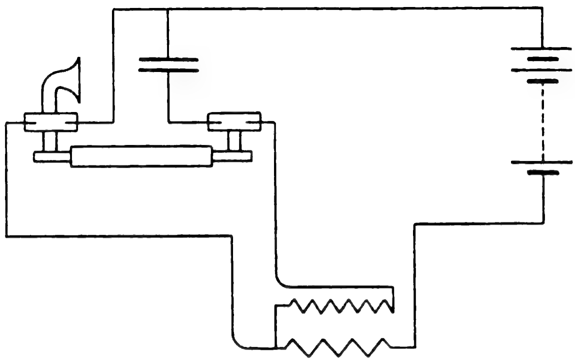


FIG. 4.

inches. The vibrations are undoubtedly conveyed through the handle. He states he has easily heard this effect through 330 feet in the open air, and I can easily believe it.

Mr. Duddell has been good enough at *very* short notice to put the current in the telephone through one of his portable oscillographs, and he gives the following approximate results—current root of mean squares 15 milliamperes at the low frequency. I understand the primary current was at 16 volts; this of course was high, and probably he used so high a pressure to enable him to get an easily observable curve immediately; the shape of the curve was as in Fig. 5; and on reversing the telephone connections the frequency about doubled.

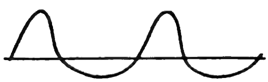


FIG. 5.

The pitch of the note appears to be determined by the length of the column of air between the two diaphragms, and the conditions of the circuit. As the periodic time of the circuit is increased the time of the note rises. To some extent the pitch is governed by the rate of the diaphragms, but I do not think this is so important a factor as the others. The main factors appear to be the angle of lag, and the length of the column of air between the diaphragms. Although the vibration is a forced one, it would almost seem that its rate is largely dependent on the free period of the circuit.

With regard to the alteration in the note when the telephone connections are reversed, Mr. Tatlow has suggested that this may be due to the fact that according to the direction of the current in the telephone its diaphragm will be moved in the same direction as, or in an opposing direction to, the diaphragm of the transmitter, and that while the former would tend to prolong the movement and so produce a lower

pitch, the latter would tend to force the rate. Although this seems probable, yet I have been unable to satisfy myself as to exactly what happens. It would appear also necessary to take into account that when the telephone diaphragm moves away from the magnet during increase in current, the self-induction of the telephone circuit is falling, due to the movement of the diaphragm, and there exists what may be compared to a negative resistance.

The humming telephone seems to be very similar to the humming

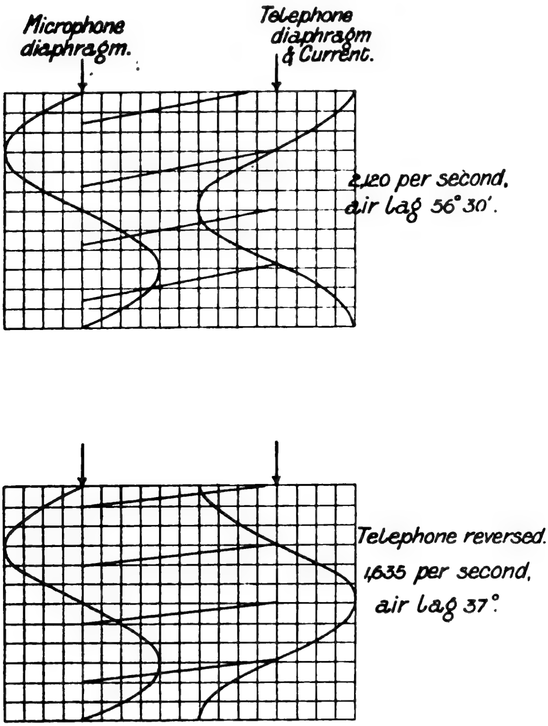


FIG. 6.

arc so ably dealt with by Mr. Duddell and shown at this meeting by Dr. Trouton, and its study by those who are provided with the necessary means of investigation would repay the labour.

With diffidence I venture to give what appears to happen :—

When the microphone diaphragm moves inwards, the current increases, but owing to lag the increase in current does not coincide with the movement of the diaphragm. The telephone diaphragm apparently more or less accurately follows the current and sends out its air waves; these waves, however, take an appreciable time to reach the micro-

phone, and there is consequently an air lag as well as an electrical lag. So far as I can at present see the high note is given when the diaphragm of the telephone moves (at the appropriate lag) in the *same* direction as that of the microphone,—thus microphone ((telephone,—and the low note is given when the motion of the diaphragms is ( ). The diagram (Fig. 6) is an attempt to illustrate this. The figures taken are N=2,120 periods per second. L=·166, R=145. The curves are drawn with a phase difference of 86° and, with a distance of 1 inch between the diaphragms the air lag is 56° 30′. The diagonal lines show the air lag. The figures with the telephone reversed are, N=1,635 L=·166, R=145, phase difference =84°, air lag =37°.

It would be desirable if one of the Masters would tell us what really is the maximum frequency which should be allowed for in telephone work. Dr. Pupin[1] says 750 periods per second is the highest that need be considered. Max Wien[2] states that the most characteristic notes of the voice lie between 500 and 3,000 per second, and Dr. Perry[3] "as an exercise" takes 1,000 as the figure; one does not associate with Dr. Perry the taking of a figure, even "as an exercise," unless he has sufficient ground for so doing.

Besides those mentioned above, I would specially wish to tender my thanks to Dr. Trouton, Mr. Sinclair, Mr. C. J. Phillips, and Mr. France. I also desire to thank Mr. J. M. Shackleton for the very great assistance he has given.

APPENDIX.

The following measurements may be of interest :—

Ader Telephone ...	Number of turns	1,120
	Resistance	145ω
	Self-induction at 10 milli-amperes	·134
	Diameter of diaphragm ...	2·12 inches.
	Thickness do. tinned	8 mils.

Deckert Microphone	Resistance at rest	10ω
	Do. high note, with circuit of induction coil and Ader telephone	23·5ω

(Both of these figures taken from ampere-meter readings.)

Induction Coil ...	Primary Turns...	380
	Primary Resistance	1·05ω
	Secondary do.	25ω
	Secondary self-induction at 22 milliamperes...	·032
	Secondary Turns	1,300

[1] *Transactions of the American Institute of Electrical Engineers*, 1900, vol. xvii., p. 255.
[2] *Ann. der Physik*, No. 3, 1901.
[3] *Phil. Mag.*, August, 1893, p. 224.

Frequency of note in three observations. Primary volts 4.	High note	2,120 vibrations per second, judged by the ear only.
	Low note	1,635 do.
	High note side but with 2·4 microfarads across telephone giving low note ...	620 do.

Amplitude of Vibration of diaphragm of Bell telephone. Primary volts 4.	High note	1×10^{-3} mm.
	Low note	6·8 " "
	High note side but with 2·4 microfarads across telephone giving low note ...	12·6 " "
	Do. Another trial...	16·5 " "

Frölich[1] gives the amplitude for a Siemens loud-speaking telephone as 35×10^{-3} mm. and V. Wietlisbach[2] gives the amplitude of a Siemens telephone (apparently not loud-speaking) for "a loud tone" as 52×10^{-6} mm. with a current of 12×10^{-4} amperes.

Mr. Porte.

Mr. A. E. PORTE said that if Mr. Gill gave some information regarding the types of instruments he had been using, the members might be better able to experiment themselves. He had given an explanation regarding the difference in note; possibly the difference in tone might be due, to a great extent, to different tones in the diaphragm of the receiver, the fundamental octave, and so on.

Dr. Trouton.

Dr. F. T. TROUTON said he would like to ask if the saturation of the iron had anything to do with the pitch of the note in the experiment shown in Fig. 4, when the field was varied. If the iron is very highly magnetised it is incapable of taking up more energy, in fact it becomes almost a non-magnetic substance in that respect, and the self-induction of the circuit diminishes so that the period would go up.

Mr. Ruddle.

Mr. M. RUDDLE considered that the tension of the diaphragm was an important factor. In Fig. 4 of Mr. Gill's paper he thought the note varied simply with the strength of the field; this strengthening, of course, increased the initial tension on the diaphragm, and in the same manner when the field was weakened, a lower note was obtained. Some years ago he carried out some experiments and found that great differences resulted from varying the tension on the receiver diaphragm.

Mr. Taylor.

Mr. J. E. TAYLOR (*communicated*): The reactive effects occurring between microphones and telephone receivers of various kinds form a most interesting subject for investigation; nor is it merely from the purely physical point of view that such investigation will repay one. There are, it would seem, sundry possibilities of practical application inherent in the phenomenon. The subject seems almost an old one; it having presented itself so frequently in laboratory and other work involving the use of telephones (very often in an awkward or intrusive way); so much so, that one feels surprised that the discovery of the effect is dated by Mr. Gill as being so recent as 1891.

That the conditions of adjustment of capacity and self-induction of the circuits concerned, as well as any natural rate of vibration which

[1] *Electrical Engineering* (Chicago), January, 1897, p. 26.
[2] *Ibid.*, p. 30.

Mr. Taylor. the diaphragms may have, are factors in determining the note emitted becomes evident at once if a microphone and receiver, with a ferrotype diaphragm common to both, be joined up, as shown in Fig. A.

In this case any alteration of capacity or inductance produces a corresponding alteration in the pitch of the note, increase of either lowering the pitch and *vice versâ*. The writer does not recollect the increase in pitch, referred to by Mr. Gill, on reversing the battery, but this should not take place if the direction of the current through the receiver is such as to oppose the permanent magnetisation, and if the pulsations of current carry the magnetic flux at the poles through the zero point. One direction gives a strong effect, and the other a very weak one. The reason for this will, it is suggested, be evident in considering the instrument next described. The writer has always found that the phenomenon is much more noticeable and effective when a transformer is used between the microphone circuit and the receiver than when both are in a common circuit. Having occasion to design a constant frequency transmitter of as simple and reliable a character as possible, as a means of actuating the magnifying telephone instrument introduced by Principal Oliver Lodge in connection with an application of the latter instrument to the Post Office System of Wireless Telegraphy, and knowing the possibilities of microphones as transmitters in this connection through the experiments on telephonic communication between the Skerries and Anglesey, and elsewhere, which the writer has carried out, it naturally occurred to him that if the proper frequency of vibration were conveyed powerfully and continuously to a microphone the undulations of current thus set up would be sufficient to set the syntonic magnifier into operation. Among various forms of constant frequency transmitters the instrument shown in Fig. B was constructed. Actually the nstrument was furnished with four microphones, all mounted similarly and symmetrically placed on the same diaphragm, the intention being to use three in multiple for transmitting, if it were found beneficial. However, it turned out that no advantage was gained by joining up more than one, owing, probably, to small differences of phase in the current undulations given out by each, which again was perhaps due to the impossibility of keeping the pressures on the diaphragms of all the microphones absolutely the same. The operation of the instrument depends, of course, on a lateral

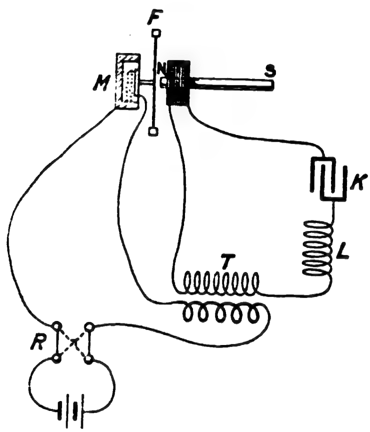


FIG. A.

F = Ferrotype Diaphragm.
K = Adjustable Condenser.
L = Adjustable Inductance.
M = Microphone.
R = Reversing Switch.
T = Transformer and Induction Coil.

vibration imparted to the wooden diaphragm through the stem of the tuning-fork, which again is communicated through small sound posts to the individual microphone diaphragms. The transformer used was about eight inches long, with a transforming ratio of about one to ten, and had an iron wire core. The magnetised tuning-fork and embraced coil form a "mono-telephone," or, as Principal Lodge calls it, a "tone-telephone" receiver. In operation the instrument proved to be Mr. Taylor.

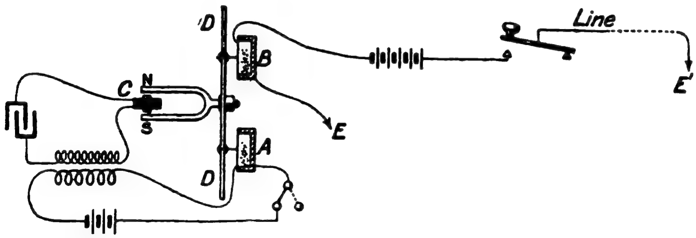


FIG. B.

A = Microphone, driving tuning-fork.
B = Microphone, producing undulations of current used in transmitting.
C = Coil driving magnetised tuning-fork.
D = Wooden Diaphragm on which fork and microphone are mounted.
E E' = Earth connections in sea.

perfectly free in its action, and self starting immediately on closing the circuit of the driving microphone, even when only one dry cell was used. With three or four dry cells it gave out a most powerful note. To obtain the best result it was necessary for the self induction and capacity of the secondary circuit to be so adjusted as to give it the same natural electrical periodicity as the fork, that is :—

Frequency of fork $= f = \frac{1}{2\pi}\sqrt{\frac{1}{KL} - \frac{R^2}{4L^2}}$, $\frac{R^2}{4L^2}$ however may be neglected giving $f = \frac{1}{2\pi}\sqrt{\frac{1}{KL}}$ or $f = \frac{160}{\sqrt{LK}}$ very approximately.

Where L = henrys
K = microfarads.

For a fork frequency of three hundred per second the best value of condenser was about 2·5 mf's, although a variation of some 50 per cent. on this value would not make a very appreciable difference, which indeed would be expected seeing that the average current in the primary circuit is a very variable quantity, as is also, in consequence, the inductance of the secondary winding of the transformer with iron core. If the value of the condenser was about doubled, or made very small, the fork either refused to start itself, or responded very feebly. If the direction of the induced current in the secondary circuit was reversed, not only did the fork refuse to respond, but, if set in motion

Mr. Taylor. mechanically, it was so rapidly and strongly damped as to be almost dead-beat.

$$\text{Taking } f = 300$$
$$K = 2{\cdot}5$$
$$\text{then from } L = \frac{160^2}{f^2 K} \text{ we get}$$
$$L = 0{\cdot}113 \text{ henry}$$

which, as nearly as could be judged, was the actual inductance of the secondary circuit. Any alteration to the fork frequency, by loading or otherwise, necessitated a corresponding alteration to the condenser to give the best result. Frequencies varying between 250 and 500 per second were tried. With a fixed fork frequency a variation of the number of cells on the driving microphone and primary necessitated a small alteration to the condenser to get the best results. Increase of power meant diminishing the capacity. This was due to the increased inductance of the iron-cored transformer following on increase of magnetising current, since magnetisation is not strictly proportional to current in iron-cored coils. The resistances of all parts of the circuit were kept fairly low. That of the secondary circuit, including the coil between the prongs of the fork, did not exceed 10ω, most of which was in the small embraced coil.

It is due to Mr. Rollo Appleyard, to mention in this connection that since constructing the above instrument the writer has been informed that the former gentleman had already described a somewhat similar arrangement under the title of a "self-maintained tuning fork," though whether the principle and construction was the same he does not know. The instrument described gives out a note of very pure tone, and has also been most successfully used by the writer in quite a different connection partly on this account. It forms an admirable laboratory adjunct for investigation and measurement of inductances at telephonic frequencies on the bridge plan, as used by Lord Rayleigh in some of his well-known investigations. By its use the increase of R in the primary circuit of a transformer on closing the secondary, as distinguished from the diminution of L, can be measured with accuracy and expedition. The two effects can be easily and simply separated one from the other by separate balancing, using, of course, a telephone receiver in place of the bridge galvanometer. This is merely mentioned as an instance of the possible applications of the principle.

It may not be generally known that in American telephone practice the microphone reaction effect is frequently applied as a test of the speaking set when the apparatus is connected up to a line. By simply holding the telephone receiver in front of the mouthpiece of the microphone a musical note is at once set up, although the diaphragms may be many inches apart.

Mr. Cook. Mr. W. W. COOK (*communicated*): At first sight the utility of an examination of the causes underlying the effects described by Mr. Gill may not be apparent, but on closer study the subject becomes so interesting and raises points of so much importance that the value of Mr. Gill's contribution is realised. In Fig. 5 Mr. Gill shows the

circuit of a micro-telephone as used in the Central Battery System. The same effect is produced with a much simpler circuit as shown below :— Mr. Cook.

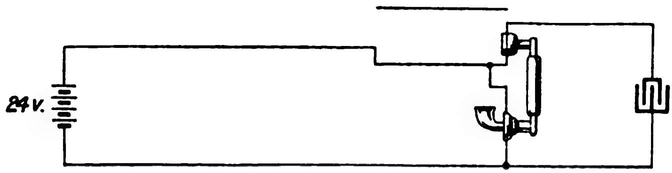


FIG. C.

the transmitter and receiver being joined up in parallel with a condenser in the receiver circuit. The resemblance between this circuit and that used by Mr. Duddell for the musical arc is very striking, but so far as I have ascertained the pitch of the note does not correspond with the time-constant of the circuit, and this lends probability to Mr. Gill's theory. Some of the effects observed with the micro-telephone differ from those obtained with transmitters and receivers not mechanically joined; for instance, the difference in note when the receiver is reversed is only two semitones, but all seem consistent with the explanation put forward by Mr. Gill. The shape of the wave observed by Mr. Duddell is very interesting, and possibly may lead to further elucidation, but up to the present I have not been able to discover any effect specially due to this.

Mr. F. GILL, in reply, gave particulars of the instruments used, which were an ordinary double pole receiver and a Deckert microphone. As regards the fundamental note of the diaphragm, he thought in the Bell receiver it was about 5,000. He did not think the iron was saturated in Figure 3, nor did he think the effect described by Dr. Trouton would have any very great effect. As regards the tension of the diaphragm he pointed out that if the diaphragm were pressed in mechanically the note went up, but in the reversal effect there was nothing to cause increased or diminished tension of the diaphragm. He thought Mr. Taylor's communication was most interesting. Probably one reason why it was possible to obtain agreement between experiment and calculation in the arrangement described was because the note to which Mr. Taylor's instrument responds was a fixture, whereas in the usual arrangement the note was free to vary, and did vary tremendously. Mr. Gill.

GLASGOW LOCAL SECTION.

ALUMINIUM: NOTES ON ITS PRODUCTION, PROPERTIES, AND USE.

By W. MURRAY MORRISON, Member.

(Paper read at Meeting of Section, December 10, 1901.)

When first asked to read a paper before the Glasgow section of our Institution, I had some doubts as to whether a general description of the Foyers Works (being the largest water-power electrical installation in the United Kingdom), with notes on its working, together with some remarks on the production of aluminium, calcium carbide, and of other electrolytic and electric reduction processes, or a description confined to one or other of these subjects, would be most interesting to members, but on considering the subject further, I came to the conclusion that the former would necessitate such a superficial survey, that I chose the latter. I intend, therefore, to make a few remarks on the production and properties of aluminium, calling attention, in doing so, to several of its uses.

In passing, although the plant at Foyers has been described to some extent on various occasions, it may not be out of place if I state briefly what it consists of. The water is derived from the river Foyers which has a catchment area of upwards of one hundred square miles. To equalise the supply two lochs have been joined together by the raising of dams and embankments, making a continuous loch of between five and six miles long, by about one half-mile broad. This loch impounds a sufficient amount of water to run the entire plant at the factory for a period of about fifty continuous days and nights, which storage, in all but the driest seasons, is amply sufficient. The water from the river Foyers is passed through a tunnel eight and a half feet diameter, cut through the solid rock, to a penstock chamber, whence, by separate cast-iron pipes, it is delivered, under a head of 350 feet, to the turbines situated in the factory, which is built on a level piece of ground on the shore of Loch Ness. Finally, the water passes out through a tail race into Loch Ness, no contaminating matter of any description being discharged into it. Seven large Girard turbines, built by Messrs. Escher, Wyss & Co., of Zurich, have been installed, driving seven vertical continuous current low-pressure Oerlikon dynamos, of 700 E.H.P. each, running at 150 revolutions per minute. Laminated copper brushes are used, having been found, after extended trials, more efficient for this type of machine than gauze brushes. The whole plant, although it requires rather special handling, runs in a most satisfactory manner and gives no trouble. For the class of work which these machines have to do no governors are required, the very occasional

regulation necessary being done by hand, and the machines can be stopped down in three minutes without undue strain on the pipe line. I shall probably excite the envy of most engineers when I tell them that this entire plant runs with a load factor, allowing for stoppages, spare power, etc., of from ·9 to ·95. Two smaller turbines of the class known as "Pelton wheels," also supplied by Escher, Wyss & Co., drive two Parker dynamos, which furnish electric light to the factory and houses close by, as well as power for a considerable number of motors. These turbines are fitted with hydraulic relay governors, giving very satisfactory regulation. Having thus briefly described the plant, part of which is employed on the production of aluminium, part on that of calcium carbide, and part on other allied industries, we may turn to the first and perhaps most interesting of these products.

Aluminium, although never found in nature in the metallic state, is one of the most widely distributed elements in the combined state, and interesting as the history of its separation is, it is only necessary here to say, that but for the application of electricity the metal would still doubtless be classed among the rarer metals, produced in small quantities by chemical methods, and sold at £1 per lb. (which was the lowest figure it was ever produced at chemically), instead of as now, at from 1s. to 1s. 4d. per lb. The transformation in the production only dates back as far as 1887, when Héroult in Europe, and Hall in America, took out patents for its electrolytic extraction. Since that date the production of the metal has increased by enormous bounds, and its use, consequent on its reduced price, has kept pace with this increase.

Prior to the electrolytic method, many others for the isolation of aluminium electrically were experimented with by different men in England, in America, and on the Continent. The electric smelting in an arc furnace of aluminium oxide, one of the most refractory oxides known, was among these methods, but entirely failed on account of the ease of formation, at the furnace temperature, of aluminium carbide, only a small amount of metal being liberated, forming minute particles amongst the carbide, the collection of which is not practicable. Reduction in aqueous solutions has also been tried, but beautiful as such methods would be, if practical, they are doomed to failure on account of the fact that even were aluminium deposited it would be in such a fine state of division that a secondary action between the aluminium and the water would at once commence, so that aluminium oxide would be formed and hydrogen liberated.

Reduction by other metals, having a higher affinity for oxygen than aluminium, has not so far been able to compete with the electrolytic method, but in this connection it is interesting to state that in 1894, Willson, of Canada, was actually attempting to obtain metallic calcium with a view to the subsequent reduction of alumina by its aid, when he discovered the commercial means of producing calcium carbide, upon the application of which such a large industry has sprung up in an exceedingly short space of time. Aluminium can be produced from any of its salts, and various processes have been proposed for using one or other of them, but so far the soundness of the original proposals of Héroult and Hall have been proved by the fact that all the practical

processes now at work adhere to the methods described in their patents of using the refractory sesqui-oxide of aluminium—alumina. Two of the other salts, *i.e.*, the chloride and the sulphide, especially the latter, offer great inducements to their use on account of the very low voltage, comparatively, required for their decomposition, but unfortunately their production is so difficult or expensive that their use has been, so far, precluded on that account. Should an easy and inexpensive method be found of producing these salts, which is certainly within the range of possibility, the effect on the cost of the production of the metal may be considerable. The following table, showing the theoretical voltages required for the decomposition of various aluminium compounds in descending order, will make the matter more clear.

TABLE I.

	Decomposition voltages
Aluminium fluoride	4·0
„ oxide	2·8
„ chloride	2·3
„ sulphide	0·9

The electrolytic methods of Héroult and Hall, known in this country as "Héroult's process," are practically identical, and consist in the electrolysing of alumina dissolved in a molten bath of cryolite, a double fluoride of aluminium and sodium ($6NaF. Al_2F_6$). Cryolite is found chiefly in Greenland, and is readily obtainable. Alumina is extracted by chemical means from bauxite, an ore more or less of the nature of clay, containing from 50 to 60 per cent. of alumina. Considerable difference of opinion exists as to the exact function of the cryolite, and as to the reaction which takes place in the furnace, but in any case the ultimate reaction takes place according to the following equation.

$$Al_2O_3 + 3C = 2Al + 3CO.$$

The oxygen of the alumina combines with the carbon of the anode to form carbon monoxide, which burns to carbon dioxide in air. The aluminium is deposited at the cathode, whence it can be tapped off or ladled out at intervals, when a sufficient amount accumulates.

Professor J. W. Richards, of the Lehigh University, U.S.A., has determined the specific gravities of the materials present in the furnace, in both their solid and fused states, as follows:—

TABLE II.

	Solid.	Fused.
Commercial aluminium	2·66 ...	2·54
„ Greenland cryolite ...	2·92 ...	2·08
Cryolite saturated with alumina ...	2·90 ...	2·35

This interesting table shows within what narrow limits the process works in this respect, and how it is only just possible for the aluminium set free to sink to the bottom, or cathode, of the furnace. It also indicates the care required to maintain the electrolyte at the most

economical temperature without running the risk of altering the relationship of the specific gravities of the materials present. Theoretically considered, the electrolytic reduction of aluminium is beautifully simple and perfect, but like many other processes, in practice innumerable difficulties are constantly experienced, and experienced even where the greatest care and attention has been bestowed. Knowledge of the symptoms of such difficulties, the anticipation of their occurrence, and the surest and most immediate manner in which to grapple with them, are matters which are bound up, of course, with the commercial success of the process, but scarcely come within the scope of my present remarks.

The power required to produce the metal being considerable, the question one is often asked: "Why is water power necessary?" is at once answered. Many statements have recently been made to the effect that steam power can, under the best conditions, be brought down to a figure at which it will compete with water power, but the author has never heard of a better offer for steam power being made than £8 per E.H.P. year (0·3d. per unit), whereas electrical power generated by water is *sold* (delivered on the switchboard of the consumer) by power companies, making apparently handsome profits, at about £4 per E.H.P. year. By an "E.H.P. year," a year of 365 days of 24 hours each is, in the above cases, referred to. Unfortunately water power is generally found in more or less inaccessible positions, so that its undoubtedly lower cost would not in many cases compensate for distance from the industrial centres, but where cost of power is the most important factor to be considered, such as in the majority of electro-metallurgical processes, there can be no question as to its economic superiority. Gas engine power plant, driven by producer gas, is now coming to the front, but it remains to be seen whether its cheapness, depending on the sale of a bye-product for which there is a doubtful market, will rival that of water power.

Aluminium produced commercially by methods other than electrolytic, could not be obtained in such a state of purity as now, when, with the use of the purest raw materials and with careful handling, metal 99·9 per cent. pure can be obtained, and the average commercial aluminium has a purity of about 99·5 to 99·6 per cent. The impurities consist entirely of iron and silicon, present in proportions as shown by the following analyses, which are representative of the metal offered for sale in this country:—

	Sample I.	Sample II.
Silicon	0·16	0.18
Iron	0·21	0·26
Aluminium ...	99·63	99·56
	100.00	100·00

With regard to the world's output of aluminium, it is interesting to look back to the year 1888, when Roscoe read a paper before the Royal Institution, in which he described Castner's chemical process for the production of aluminium, and the works of the Aluminium Company at Oldbury where this process was in use. He pointed out that the works

were so large that they were capable of an output of as much as fifty tons per annum! The combined production of the present year of the English, American, French, and Swiss aluminium producing companies is estimated at rather more than 5,000 tons, or 100 times as much as Roscoe thirteen years ago looked upon as a phenomenal production.

Perhaps the two metals which aluminium is most likely to replace, to a certain extent, are copper and tin, the world's use of which for the last year was respectively 497,000 tons, and 79,200 tons, the amount of aluminium used being only equivalent to 0·87 per cent. by weight, or 2·85 per cent. by volume, of these combined figures. It will, therefore, be seen what possibilities there are for the extension of this already considerable electrolytic industry, should even a further small percentage of these metals be replaced by aluminium.

Like the majority of new things, aluminium has suffered from too much being expected of it, and its use having been advocated in a haphazard manner for a variety of purposes, where a knowledge of its properties and limitations would have precluded even its trial. On the other hand, it has suffered from undue depreciation, and there are numerous cases in which its use would prove a decided advantage, and cases in which it replaces, with saving in first cost, other metals, when it has the qualities required for the special nature of the given work. This being so, notes on its outstanding properties and the uses to which these properties make it applicable cannot but be of interest.

The most marked property of aluminium is undoubtedly its low specific gravity, which property brings it into competition with other metals. Table III., giving the specific gravities, equivalent weights, and equivalent prices for equal volume of the common metals, shows this clearly.

TABLE III.

Metal.	Specific gravity.	Weight for equal volume.	Cost per ton.	Comparative cost of ingot metal for equal volume.
			£	
Aluminium	2·56	1	148	1
Zinc	7·00	2·73	17·5	·323
Tin	7·30	2·85	115	2·21
Cast Iron	7·40	2·89	3	·0586
Brass (50 per cent. alloy)	8·30	3·25	50	1·10
Nickel	8·50	3·32	196	4·40
Copper...	8·63	3·37	66	1·51
Gun Metal	8·73	3·41	84	1·94
Lead	11·40	4·45	12·5	·377

It will be seen from these figures that for equal volume aluminium would weigh only 37 per cent. of the next lightest metal in common use, and that as regards cost, only three common metals are lower.

The tensile strength of pure aluminium, cast, is from five to eight tons per square inch, with a 2 to 3 per cent. elongation, and rolled or drawn, up to seventeen tons per square inch, with 2 to 4 per cent. elongation. It has a low melting point (625 degrees C.), and can easily be worked, cast, extruded, rolled, forged, drawn, spun, machined, etc., with attention to certain simple precautions, which are now well known and easily given effect to. Its shrinkage in casting is high, and compares with other metals as shown in Table IV.

TABLE IV.

Shrinkage of Castings.

Zinc	·3125 inches in a foot	=	2·60	per cent.
Lead	·3125 „ „	=	2·60	„
Aluminium	·2031 „ „	=	1·69	„
Copper	·1875 „ „	=	1·56	„
Brass	·1580 „ „	=	1·32	„
Iron Pipes	·1250 „ „	=	1·04	„

Aluminium ranks third among metals as regards malleability, and sixth as regards ductility, sheets can be hammered down to ·000025 inch thick (replacing silver leaf), and wire drawn down to ·004 inch diameter, and even finer. It has a high coefficient of thermal conductivity, standing fourth on the list of metals in this respect, which property, added to the fact that it is only affected very slightly by acids, and that any of its salts, formed by its partial decomposition, are all absolutely harmless, have made it a valuable substitute for other metals for cooking utensils, surgical instruments, etc.

It is less affected by dry or damp air, at any temperature, than any of the ordinary metals, and may be melted in air, with only the formation of a very thin film of oxide which tends to prevent further oxidisation (the oxide of aluminium being one of the most stable compounds known), and which also renders the metal non-volatile. This film appears on the surface of the metal instantaneously at any temperature, and is a very interesting, as well as useful, characteristic. When under the action of a burnisher the film is rubbed off the surface, and the metal raised to a higher polish; the instant the burnishing tool leaves a given point on the surface of the metal a film of oxide forms, and as it were fixes the surface of the metal at the higher degree of polish. An example of the formation of the oxide film is seen in the case of metal when being cast. If, when being poured into a mould, rather more than the full amount required to fill the mould is poured in and the balance runs over the side, the tenacious oxide film, adhering to the surface of the metal in the mould and to the portion which has run over the side, forms a tube acting as a syphon, which, if not broken in time, syphons out a considerable quantity of the metal.

The highly refractory nature of aluminium oxide and, consequently,

the great affinity of the metal for oxygen, has been taken advantage of by Dr. Goldschmidt, who recently introduced a process, based on this property, for the production of high temperatures. By means of a mixture of finely divided aluminium powder, and a less refractory oxide than alumina, Dr. Goldschmidt is able to obtain some of the rarer metals, otherwise difficult to isolate, as well as the more common ones. The process is started by the ignition of the mixture by means of a magnesium ribbon, the oxygen of the oxide present combines with the aluminium to form alumina, thus freeing its metal, the reaction spreading at once over the whole mass, and raising it to a high temperature. Iron being easily reduced from its oxide by this process, Dr. Goldschmidt has applied it to the welding of rails and pipes, to the repairing of defective and broken steel castings, toothed wheels, etc. His process is now being introduced commercially, and apparently may prove to be a highly useful one.

A further application of aluminium, forming one of the largest applications yet found for it, consists in its addition to iron, steel, and brass castings, where again its high affinity for oxygen is taken advantage of. To the casting ladle of molten iron or steel, a small proportion of aluminium (2 to 5 lbs. per ton) added has the effect of reducing the blowholes, by combining with the occluded gases, thus rendering the metal much more fluid, and ultimately more ductile, tougher, and of greater homogeneity. No aluminium remains in the metal, and in foundries where it is used, the "waster" castings are said to be less by a very large percentage. For this purpose aluminium has twenty times the deoxidising power of silicon.

A large field of usefulness is found for alloys of aluminium, which are generally divided into two classes. First: Light alloys, or those in which not more than about 10 per cent. of other metals are added. The specific gravity of these alloys is raised to from 2·7 to 2·8, but the tensile strength is increased to from eight to twenty-four tons per square inch with a 2 to 20 per cent. elongation, according as the metal is cast or rolled. Second: Heavy alloys, or those in which aluminium is present up to only about 10 per cent. Bronzes, which find considerable application in the Arts, are the principal alloys in this class. They have a specific gravity of from 7·5 to 8·4, and a tensile strength of from twenty-five to forty-five tons per square inch, with 10 to 30 per cent. elongation.

Aluminium finds advantageous use in military and naval equipment, in the building of motor cars, and in many less known fields, but the one which is more interesting to our Institution is its application in electrical work. Lately, owing to the high price of copper and the decreased price of aluminium, the use of the latter as a bare wire conductor has received a good deal of attention. As some hundreds of tons have already been used for that purpose, and as the further divergence of prices may in the near future still more accentuate the already existing difference in favour of aluminium, it would seem advisable that all possible information with regard to the merits of the rivalry between these two metals should be collected. Bearing this in view the following notes and comparisons may prove of some value.

Numerous tests of the specific resistance of pure aluminium have been made by Lord Kelvin and others, proving it to have a conductivity (copper being 100) of from 60 to 65 per cent., depending on the purity of the metal tested. A recent determination by Professor E. Wilson,[1] of King's College, London, of aluminium 99·55 per cent. pure (the average purity of the commercial metal) shows it to have a specific resistance of $2·762 \times 10^{-6}$ legal ohms, at 15 degrees C., with a temperature coefficient of ·00393, and a linear coefficient of expansion of ·000023, between 16 and 100 degrees C. Comparing this specific resistance with that of copper (Matthiessen's standard, $1·696 \times 10^{-6}$ ohms at 15 degrees C.) we get its electrical conductivity equal to 61·4 per cent. Comparison of the principal properties of copper and aluminium wire is given in Table V., the conductivity of the latter having been taken in a round number slightly lower than the actual figure given above.

TABLE V.

Comparative Figures of Copper and Aluminium Wire.

	Copper Wire.	Aluminium Wire.
Specific gravity	8·93	2·65
Conductivity	100	61
Section for equal conductivity	1	1·64
Diameter " "	1	1·28
Weight " "	1	·485
" " section	1	·297
Tensile strength for equal section	1	·46
" " " " conductivity	1	·75

It will be seen that for equal conductivity an aluminium wire must have, compared with a copper one, a section increased by 64 per cent. (diameter increased by 28 per cent.), but that a saving in weight of 52 per cent. is obtained, which, when transport is considered, is valuable, and which also admits of fewer and lighter poles being used as supports for overhead wires. For equal conductivity aluminium has only three quarters of the tensile strength of copper, which, especially with small wires, may in some cases be insufficient. For this reason alloys are frequently used, by which means the tensile strength can be increased to equal or surpass that of copper, with, however, a corresponding decrease in conductivity, and increase in weight. Alloys equalling the strength of copper for equal conductivity with a reduction of from 1 to 2 of percentage conductivity, and an increase of only about 2 per cent. in weight, have been produced, and extensive experiments in this direction are still being conducted.

Table VI. (p. 408) shows for the different market values of copper and aluminium, when a saving can be effected by the use of either the one or the other as the case may be, for, from the data in Table V., it is clear that for any given price of copper there is a corresponding price at which it becomes less costly to use aluminium, while securing equal efficiency, and *vice versâ* copper for a given price of aluminium.

[1] See above (Professor Wilson's paper), p. 321.

TABLE VI.

Price of copper wire in pence per lb.	Equivalent price of aluminium for equal section in pence per lb.	Equivalent price of aluminium for equal conductivity in pence per lb.
6	20·2	12·4
7	23·6	14·4
8	27	16·5
9	30·3	18·6
10	33·7	20·6
11	37	22·7
12	40·4	24·7

The current price of copper wire being about 10d. per lb., 20·6d. per lb. could be spent on aluminium wire for equal efficiency. As its current cost is about 1s. 6d. per lb., it will be seen that for bare overhead conductors aluminium wire is the cheaper of the two by about 13 per cent., and has the added advantage of saving over 50 per cent. in the weight to be dealt with.

For the transmission of a given current at a given loss, aluminium having a larger surface than copper would have, the heating effect of C^2R losses ought to be smaller. One of the initial difficulties in the use of aluminium conductors was the making of a satisfactory joint. Many solders have been proposed for aluminium, only one or two of which have apparently proved satisfactory, but their manipulation, even if satisfactory, scarcely admits of their application in the field, so it is to mechanical jointing that one has to look. A number of such joints, having the requisite mechanical and electrical properties, are in constant use, and the description of several of them may be of interest. In America, the most generally adopted joint is known as the "McIntyre joint," and consists of a flattened tube of aluminium into which the two ends of the wire are inserted, the whole being given two to three complete twists.

At Foyers we have many tons of aluminium wire, cables, and strip in use, and have designed various joints for use in connection with them. With strip the ends are overlapped, holes drilled through and through, and riveted up tightly with aluminium rivets. It may be here said that aluminium, being a highly electro-positive metal, no other metal should, if it can be avoided, be used in contact with it, otherwise there is the risk of electrolytic action setting in.

We have a telephone line of No. 12 S.W.G. wire running a distance of about six miles over exposed country, supported on poles placed about fifty yards apart. The joints in this case are made by twisting the ends of the wire round each other, and bending round the loose ends outside the main wire to form a semicircle with a radius of about one inch. The two ends are butted together, held by pliers, and welded in the flame of a blow lamp. The joints in this line have given no trouble, but the wire in the most exposed positions has broken several times during very high winds. The wire being of pure aluminium and being of so small a diameter accounts for this, and there

is no doubt that for telephone or telegraph lines of small diameter, it is necessary to use an alloy. Comprehensive experiments with the view to finding a suitable alloy have been, and are being, carried out, lines being also under trial at the present moment by the Post Office authorities and others. It is believed that solutions of the problem have been arrived at, and no doubt aluminium wire for these purposes will be ultimately as successful as copper ones, the success of which, it must be recollected, also entailed endless difficulties and failures in the early days.

The most interesting line is a bare overhead transmission line of ·38 in. diameter, having a total length of about 5,500 feet. The wire is bound by means of thin aluminium wire to insulators carried on poles about forty yards apart. This line was erected between four and five years ago, is in constant use, and has given absolutely no trouble in any respect. Being primarily an experimental line, the wire was put up in short lengths, so as to give a large number of joints. There are twenty-eight of these of different kinds, the best of which I may describe. The two ends of the wires are bent round each other—or simply butted together—they are then surrounded by a cigar-shaped mould in two halves, which are clamped together, and molten aluminium run in at a hole in the top of the mould. The mould is then removed and the joint trimmed. Aluminium having a low melting point, the metal required for this joint can easily be melted in a hand-ladle on the fire of a portable forge. Tests of the electrical and mechanical properties of these joints prove that they are more than equal to those of the original wire. Samples of some of the above joints are exhibited.

For connections, flexible and strip, between dynamos and furnaces, a large number of tons of aluminium are in use with the most satisfactory results. This is a case in which, even were no actual saving in first cost secured, it would still be preferable to use aluminium in place of copper, for the saving in labour in handling is most important.

In America much more has been done than in this country in the way of utilising aluminium wire, and that the experience of American engineers is satisfactory is proved by the fact that aluminium has been used, or is specified, for all the later large transmission schemes. Among the larger of these schemes may be mentioned the 12,000 H.P. transmission from the Snoqualmie Falls to the cities of Seattle and Tacoma, being respectively thirty-two and forty-four miles transmission, the 13,000 H.P. forty-three miles transmission from the Mokelumne River to Stockton, the 2,000 H.P. thirty-three mile transmission from Tariffville to Hartford, Connecticut, the seventy-six miles of wire between Kansas City and Leavenworth, and the important transmission scheme from Niagara Falls to Buffalo, a distance of about thirty miles. In this latter line, where with copper wires the poles were spaced seventy-five feet apart, the average distance with the aluminium lines has been increased to 112½ feet, representing a saving in poles of over 30 per cent. The tests published in regard to some of these transmission schemes have been very satisfactory, and the figures closely agree with those given in this paper.

When first asked to put down aluminium instead of copper, I felt great misgivings, having the usual prejudices in favour of the latter, but after nearly six years' practical experience of the handling and use of aluminium wires my opinion is entirely altered, and I am fully convinced of the advantage to be gained by their use, provided always that the first cost compares favourably (due consideration being also given to the reduced weight) with that of copper for the same conductivity.

With regard to insulated cable in low-tension work, aluminium cannot compete with copper at present prices, unless the cost of dielectrics falls very considerably, as in such cases the radial depth of insulation is determined almost entirely by considerations of mechanical strength, durability, and Board of Trade regulations. Should the price of copper increase, or that of aluminium diminish, as it seems quite likely to do with a more extended use, then there will no doubt be competition. In order to see of what order prices would have to be for such a contingency to arise, the author has taken the case of armoured, lead covered, paper insulated cables, of the highest class, ready for laying directly in the ground, and found that, with copper at 10d. per lb., aluminium wires, insulated and sheathed in a similar manner, of the same conductivity as copper (*i.e.* 1·64 times the section) would have to be obtainable, to equal the cost of the copper cables, at from 14·5d. to 16·5d. per lb. for sections equivalent to from 1 to 0·2 square inch of copper. In vulcanised rubber cables there would be a saving in total weight, averaging about 15 per cent., but in lead-covered cables the weight for equal conductivity would be increased by an almost similar amount, the insulation and sheathing forming, as it does, so large a percentage of the total weight of the cable.

The case of high-tension cables is, however, on a different footing, and is a matter of extreme importance, in view of the many power Bills which have recently passed through Parliament. The lack of proportionality between the radial depth of insulation in cables and its dielectric strength was pointed out by Mr. Swinburne in June, 1899, and has since been very fully dealt with by Mr. Mervyn O'Gorman in his paper[1] read before the Institution in London in March of this year. Mr. O'Gorman there shows conclusively that, for a given voltage of supply, there is a certain section of copper which gives the cheapest cable. Above this size the increase in price is approximately proportional to the section of copper, while below this section the increased radial depth of insulation necessary, on account of the smaller conductor, makes the cable more expensive. Thus, in one of Mr. O'Gorman's curves, it is shown that for 20,000 volts, and paper insulation with lead sheathing, 0·4 square inch is the section of copper, which gives the cheapest cable. Suppose in a given case the voltage of supply is 20,000—a not improbable figure in view of the considerable areas which some of the power companies are to supply—0·4 square inch will then be the section giving the cheapest copper cable it is possible to get. Suppose, however, that a feeding point is to be supplied with a certain quantity of power, and that the distance, and permissible losses, are such that 0·4 square inch of copper is a larger

[1] This Journal, Vol. 30, p. 608.

section than is required under the circumstances, and that 0·25 square inch of copper would be sufficient. Then, by substituting 0·4 square inch of aluminium for the copper, we get a cable which fulfils the necessary conditions, and costs from £150 to £170 less per mile than the copper cable, apart from saving in weight, which reduces the cost of laying. Thus for all high voltages there are certain circumstances under which aluminium cables are considerably cheaper than copper. This point deserves careful consideration by those responsible for the installation of high-tension transmission lines.

The oxide film on aluminium, above referred to, may be found to have an important bearing in such cases, as its resistance, in a dry state, has been found by Professor Wilson to be very high. The tensile strength of the wire in insulated cables would not be a factor, so that in all cases pure aluminium would be used.

The electrical conductivity of different metals as given in Table VII., some of which are used for connections, parts of switch gear, brush holders, etc., coupled with their relative costs as given in Table III., would seem to indicate the superiority of aluminium for these purposes, and indeed it is now being used to a considerable extent in this direction. Aluminium it may also be stated is non-magnetic.

TABLE VII.

Metal.	Electrical Conductivity.
Copper (pure)	100
Silicon bronze	98
Copper-Silver (50 per cent. alloy)	86·6
Aluminium	61·4
Zinc	29·9
Brass (35 per cent. zinc)	21·5
Iron wire	16
Tin	15·4
Lead	8·9
Nickel	7·8
Antimony	3·9

Table VIII. (see p. 412) showing the relative weights and resistances of aluminium and copper wires of different sizes is given for reference.

Prof. M. MACLEAN (Chairman) said that a member had asked him if it would be competent to discuss the paper[1] read by Professor Ernest Wilson before the parent Institution the previous week, the subject matter of which also dealt with aluminium. He thought it would be quite competent to make remarks on that paper as well as on the paper Mr. Morrison had just read. He therefore invited the members to make remarks on either paper. Professor Maclean.

Mr. W. B. SAYERS said there were one or two points in Professor Wilson's paper to which he would like to call their attention. With regard to the statement that the conductivity of some alloys increased when heated from 0° to 100° C., this seemed to read as though Professor Mr. Sayers.

[1] See above (this volume), p. 321.

TABLE VIII.

No. S.W.G.	Dia. in inches.	Area in square inches.	Weight in lbs. per mile.		Length in feet per lb.		Resistance per mile in Ohms.	
			Aluminium.	Copper.	Aluminium	Copper.	Aluminium.	Copper.
0000000	·500	·196	1,194	3,981	4·42	1·33	·353	·215
000000	·464	·169	1,018	3,426	5·18	1·56	·410	·250
00000	·432	·147	891·5	2,972	5·92	1·78	·476	·289
0000	·400	·126	764·4	2,547	6·91	2·07	·554	·337
000	·372	·109	661·1	2,204	7·99	2·47	·642	·390
00	·348	·0951	578·5	1,926	9·13	2·74	·731	·445
0	·324	·0824	507·8	1,671	10·40	3·16	·840	·513
1	·300	·0707	429·9	1,433	12·28	3·68	·980	·597
2	·276	·0598	363·7	1,212	14·52	4·37	1·16	·707
3	·252	·0499	304·1	1,012	17·36	5·22	1·40	·850
4	·232	·0423	253·3	855·6	20·85	6·17	1·64	1·00
5	·212	·0353	214·7	715·7	24·59	7·38	1·97	1·20
6	·192	·0290	176·1	587·0	29·99	8·99	2·40	1·46
7	·176	·0243	148·0	493·3	35·68	10·70	2·86	1·74
8	·160	·0201	126·3	407·5	41·79	12·96	3·45	2·10
9	·144	·0163	99·1	330·5	53·26	15·98	4·28	2·60
10	·128	·0129	79·5	260·9	66·44	20·23	5·38	3·28
11	·116	·0106	63·0	214·3	83·82	24·63	6·56	4·00
12	·104	·00849	48·7	172·3	108·4	30·64	8·20	4·98
13	·092	·00665	39·6	134·8	133·2	39·17	10·5	6·36
14	·080	·00503	31·4	101·4	168·0	52·09	13·9	8·42
15	·072	·00407	24·8	81·1	211·9	65·10	17·1	10·4
16	·064	·00322	19·8	64·9	267·2	81·38	21·7	13·2
17	·056	·00246	15·7	49·9	336·9	105·9	28·2	17·2
18	·048	·00181	10·9	36·5	482·6	144·7	38·4	23·4
19	·040	·00126	7·81	25·5	675·7	207·4	55·2	33·6
20	·036	·00102	6·20	20·6	851·8	255·9	68·1	41·6
21	·032	·000804	4·92	16·4	1,074	322·3	86·3	52·6
22	·028	·000616	3·73	12·5	1,414	423·1	113	68·6
23	·024	·000452	2·74	9·16	1,929	576·4	154	93·5
24	·022	·000380	2·45	7·70	2,154	685·7	182	111
25	·020	·000314	1·94	6·36	2,716	830·2	222	135
26	·018	·000254	1·54	5·14	3,425	1,027	272	166
27	·0164	·000211	1·22	4·28	4,318	1,234	328	200
28	·0148	·000172	1·03	3·49	5,106	1,514	403	246
29	·0136	·000145	·884	2·95	5,974	1,796	478	291
30	·0124	·000121	·730	2·44	7,233	2,164	576	351

Wilson had found a positive coefficient for conductivity with temperature increases, but this was not borne out by the table at the end of the paper. Perhaps Mr. Morrison could make this clear. Referring to Mr. Morrison's paper, there had been a great deal made of the difficulty of soldering aluminium, yet he (Mr. Morrison) told them without a word of explanation that the wires were welded with a blow lamp! Why trouble about soldering if welding was such a simple matter? From the way in which the samples of wires with welded joints were twisted together he imagined that the welded joint was deficient in mechanical strength. He asked Mr. Morrison to give them some information as to the energy required in producing aluminium—how many horse-power hours were required per ton of metal, for instance? Mr. Sayers

Mr. W. McWhirter said that when they came to use aluminium for conductors there were a good many points which required careful consideration. Its breaking weight, as compared with either iron or copper, was very much less, and the coefficiency of lineal expansion for temperature was much higher. It would hardly, therefore, be possible to erect aluminium lines on the same poles with copper or iron; of course, for electrical transmission this would not be necessary. The suggestion made in the paper that the spans for aluminium lines might be much longer than for other metals he was afraid would not hold good, as the difference of expansion would make a very great difference in the sag, using aluminium. In addition to this the aluminium could not be pulled up to much more than half the stress usually obtained with iron or copper, and, further, the additional area exposed to wind and snow would be liable to throw greater stress upon the aluminium line. It would therefore be advisable to decrease the distance between the poles where aluminium lines were erected. The information given by Mr. Ernest Wilson in the paper read last week before the Institution in London pointed, however, to the possibility of the above difficulties being effectively met by the use of an aluminium alloy, and seeing the breaking weight of the material can be increased by 33 per cent. with a very slight reduction in the conductivity of the metal, it appears that we may look forward to considerable use being made of these alloys. The heavy loads to which aërial lines are exposed both from storm and snow must be fully provided for, and he remembered one very remarkable snowstorm which occurred over twenty years ago when a railway line under his supervision had, in a length of less than one hundred miles, nearly thirty miles completely wrecked. Mr. McWhirter.

With reference to the remarks of Mr. Sayers regarding the increased conductivity due to annealing, this was, he thought, explained by the fact that the metals after annealing were allowed to cool before these tests were taken. He did not think the results were found while the metals were at the higher temperature.

There could be no doubt the field for aluminium is extending very rapidly, and recently during a journey in India he had noticed how extensively aluminium was used in a great variety of ways throughout that vast country, more especially, however, for cooking utensils, where it appeared likely that in a few years copper would be quite displaced for this purpose.

Mr. Mavor.

Mr. H. A. MAVOR said his firm had begun to use aluminium in their foundry, and the results had been very satisfactory. They experienced some difficulty, however, in machining it. He noticed that Mr. Morrison's paper, while giving very full data with regard to aluminium, said nothing about its crushing strength. It would be interesting to have a few facts with regard to this. Mr. Morrison had mentioned the cost of £4 per H.P. per annum. Mr. Mavor gave the following particulars of the best case in his knowledge of low cost of power production. The information was given to him by the manufacturer direct. The questions addressed to the manufacturer are given below, together with answers. The cost given works out to about ·093 pence per horse-power per hour for coal, wages, oil and stores. It will be noted that the cost of the coal is not particularly low. These particulars are taken from a paper read to the Institution of Engineers and Shipbuilders in Scotland on 22nd March, 1898:—

What is your manufacture?—Spinning.
What is the source of power? Coal or water power?—Coal.
At what price delivered can you obtain coal for steam raising?—5s.
At what price delivered can you obtain anthracite coal?
At what price delivered can you obtain coke?
What size of boilers do you use?—No. 3; size, 30 ft. by 8 ft.; type, Lancashire 2-flue.
What engines do you use?—No. 1; size, 1,200 H.P.; type, vertical triple expansion.
What is your steam pressure?—140 lbs.
Do you use mechanical stokers?—No; moveable bars.
Do you use forced draught?—No.
Do you use condensers?—Yes; one.
Do you use economisers?—Yes; 320 pipes.
How many hours per annum does your factory run?—2,800.
What is the total I.H.P. of your engines at maximum load?—933.
What is the total I.H.P. of your engines at normal load?—840.
What part of the power is expended in driving shafting and belting?—200 I.H.P.
What is approximately the loss of pressure in steam pipes to isolated engines?—3 lbs.
At what do you estimate the cost of power per horse-power per annum?—14s. (State whether inclusive or exclusive of depreciation on cost of engines, repairs, etc.)—Exclusive.
What is your total coal bill per annum for steam raising?—£586.
What is your total oil bill per annum for steam engines?—£35.
What is your total petty stores bill per annum for steam powers?—£30.
What is your total water bill per annum for steam raising?—£53 (interest and ground rent for reservoirs).
What is your total wages bill per annum for steam raising?—£83 15s.
What is your total wages bill per annum for engine tending?—£113 15s.

Mr. Chamen.

Mr. W. A. CHAMEN, in thanking the author, said that in common with some of the other speakers he was a little disappointed that Mr. Morrison had not said more about the methods of producing aluminium. He had hoped that Mr. Morrison would have shown them a sectional view of one of his electrolytic furnaces on the screen. In this way he might have given them an outlet for using some of their spare horse-power during the summer months.

Mr. Bubb.

Mr. H. J. BUBB said he had been asked to make a few remarks as a user of or worker in the metal, at a later stage than the author deals

Mr. Bubb.

with in practice. For electrical work an illustration of its use may be quoted in the fact that the wiring of the outside arc lighting at the recent Glasgow Exhibition was entirely done with bare aluminium wire, erected under the superintendence of the speaker and his colleagues. The instructions given by the engineer to the Exhibition were that a drop of ten volts was to be the maximum, the lamps being arranged ten in series across mains, having a difference of potential of 510 volts. Some of the circuits were inevitably of considerable length, and for these the gauge of aluminium wire employed was No. 3 S.W.G., while for the rest No. 7 was sufficient to ensure the necessary conductivity for the maximum drop named. Not the slightest difficulty was found in regard to the strength of the wire, but on the other hand this strength was found to be altogether out of proportion to the strength of the fixtures for the insulators originally erected on the arc lamp standards, which were subsequently considerably modified. Joints were avoided where possible, and in some cases, these being inevitable, were made by the simple process of butt welding, and proved perfectly satisfactory. The wire has been removed at the close of the Exhibition and no appreciable deterioration seems to have taken place. The process of welding aluminium which does not seem to be familiar to some of the speakers is one of the most simple operations possible, in fact so simple that a labourer of ordinary intelligence is capable of making a satisfactory joint after half an hour's practice. The easiest method is to impinge the flame of a blow-lamp or blow-pipe on to a firebrick or piece of foundry coke, in a similar manner to the oxyhydrogen jet on to a lime cylinder. The two ends of the wire to be jointed, roughly cleaned with a piece of sand or emery paper, are brought together in the flame in such a position that one side is heated by the flame direct and the other by the flame reflected back, so to speak, by the hot surface of the coke or fire-brick. At the instant of semi-fusion, which is easily noticed, the ends are pressed together and the wire steadily removed from the flame and held until the metal has completely set, which only takes an instant with small sizes. If the wires have been truly butted and held steadily throughout the operation, the result, when the swollen portion is filed and cleaned off, cannot be distinguished from the rest of the wire, and a perfect electrical joint results. A drawback to using this joint for an overhead line, where there is considerable tension on the wire, is that the heating of hard drawn aluminium anneals it, and while increasing its conductivity decreases its strength by about 30 per cent. A wire jointed in this manner, and strained to breaking point, will be found to give way not at the joint itself, but within ¼ in. to ½ in. on either side of it, according to the thickness of the wire, the reason being that the metal at these points has been absolutely annealed, and is accordingly weaker than the rest of the line. Accordingly, devices to increase the mechanical efficiency of the joint, such as shown by the author of the paper, are usually employed in practice.

Mr. Martin and Mr. Mavor have inquired as to the lubricant recommended for use in machining aluminium. I believe that Mr.

Mr. Bubb. Martin's firm already use the lubricant that seems to be the best yet discovered, viz., half turpentine and half water. With this the metal can be machined with very nearly the same facility as brass, if the tools are ground to the rake, etc., that the engineer finds most suitable for the work in hand, and a good stream of the liquid is allowed to play on the point of the tool. The harder or stiffer alloys, however, machine perfectly well dry, and very little benefit is found by the use of any lubricant in their case. Bolts and studs should, wherever possible, be chased and not screwed in dies, and in cutting any thread it is always best to keep a flow of lubricant on the work. For drawing through a die, horse-grease, tallow, or suet is recommended, a good quantity being employed, care being taken never to expose a dry surface to the die, which otherwise tends to become coated with the metal and will no longer give a clean surface to the rod or wire.

Professor Jamieson. Professor A. Jamieson wrote that he was pleased to learn that neither the famous "Falls of Foyers" nor the foliage of the surrounding district have suffered by the aluminium works. Knowing Mr. Morrison as he did, not only as a careful painstaking student, but as an assistant who recorded very fully everything he tested, he could not help observing that his paper must have been subjected to considerable "press censorship" by his Company. For example, he gave the E.H.P. and the revolutions per minute of the Oerlikon dynamos, but omitted to state either their voltage or current. Again, he did not state the average potential difference between the terminals of the electrolytic furnaces at the beginning of, during, and towards the end of smelting a charge. Further, he gave no sectional drawings and description of the construction and working of these furnaces. And so with many other points. No doubt, the present severe foreign competition caused the British Aluminium Company to keep secret any new specially useful improvement which they did not find necessary to patent or publish. They were, however, willing to let their manager explain the manufacture in a general way and for him to give just as much knowledge of the purified article as might be interesting and useful to buyers of their ingots. Members of this Institution were, however, desirous of knowing something more than this, if it could be abstracted from those who know. The first statement in the paper regarding the working of the turbo-generators, which excited our appreciation, was that they worked night and day without governors in the most satisfactory manner, with a net "load factor" from 90 to 95 per cent.; and, that these machines could be stopped, when necessary, in three minutes without causing any undue stress on the supply-pipes. The second most important statement was, that the price per pound had been reduced from £1 to 1s. since the introduction of the Héroult-Hall electrolytic process. And the third, that aluminium can be produced commercially, of 99·5 to 99·6 per cent. purity. These were remarkable results and all accomplished within the past few years. Mr. Morrison has very clearly pointed out, that in the reduction of aluminium by the above-mentioned process (see Table II.), nature somehow or other automatically came to its aid, by causing the specific gravity of the *fused* commercial aluminium to be higher than either its Greenland cryolite

Professor Jamieson.

flux or cryolite when saturated with alumina; whereas, in the solid state the reverse is the case! The difference of their specific gravities is, however, so very slight that the process becomes a very delicate one. Mr. Morrison did not state the actual cost per E.H.P.-year of the water-power at Foyers, but he led one to infer that it is less than £4 per annum of 8,760 hours' work. Mr. Morrison gave all the best reasons why aluminium is now recognised as the most valuable substitute for iron, copper and other metallic cooking utensils, but he (the speaker) had been astonished some time ago to find upon a troop-ship by far the greater proportion of the pots, pans and kettles were made of aluminium; and that the troops would be supplied with similar, but of course smaller and lighter, cooking appliances when encamped on the veldt. He had recently learnt that all sorts of light military necessaries, both for home and abroad, were now being ordered, and that these things served their purposes better than if constructed of any other metal. Mr. Morrison, when dealing with the "specific resistance of aluminium," and also Professor E. Wilson, used the term "legal ohms"; but this so-called *Legal Ohm* was now out of date. It was the Ohm proposed at the Paris Congress of Electricians in 1884, and was entirely superseded by the '**Ohm**' as defined by the Board of Trade.[1] Moreover, Professor Wilson had referred to Matthiessen's standard, but every one had agreed to adopt the "Report of the British Representative Committee on Copper Conductors," issued in December, 1899, as being the most reliable. He suggested that Mr. Morrison should change Professor Wilson's results into Ohms, when forming the tables, about which he was just going to make a few suggestions. Mr. Morrison, on p. 408, had referred to solders for aluminium, but on page 38 in "Notes on Aluminium and its Alloys" as issued by the British Aluminium Co., Ltd., the following sentence occurs:—"Soldering has so far been a difficult task, but the British Aluminium Company has a hard and a soft solder entirely answering the purpose." Then follow rules how to use these solders, but never a word as to their composition! Perhaps Mr. Morrison could, in his reply, furnish the composition of these, the best solders for aluminium and how to use them. The information given in the paper regarding aërial conductors was interesting, instructive, and encouraging. The speaker suggested that Mr. Morrison should collect all the known reliable and most important data regarding aluminium, and all the other most useful metals, into three separate tables, printing the data for aluminium and its chief alloys, copper and iron, in distinctive types so that these could be easily compared. Table I. should have as a heading, "Physical, Chemical and Metallurgical Data"; Table II., "Mechanical Data"; and Table III., "Electrical and Commercial Data." By so doing, and giving the authorities quoted, he would confer a great benefit upon chemists, engineers and electricians, and save them, as well as others, much time and vexation in looking up numerous disjointed tests and tables. No one could have a better opportunity of doing so, and from his position as manager and

[1] See Munro and Jamieson's *Pocket Book of Electrical Rules and Tables*, 15th edition, 1901, pages xxix., xxxi., 15, 264, etc.; see Index.

Professor Jamieson. engineer of the British aluminium works, his results and quotations would be accepted as reliable.

Mr. Morrison. Mr. W. MURRAY MORRISON, in replying to the remarks made upon his paper, said: I am very pleased that Mr. Sayers has mentioned Professor Wilson's highly instructive paper read before the Institution in London a few days ago. The "negative temperature coefficient," however, which Mr. Sayers attributes to aluminium wire from his rendering of the text of Professor Wilson's paper is, I am sorry to say, imaginary. In dealing with pure aluminium, Professor Wilson states that he finds no change in specific resistance after annealing, but gives a temperature coefficient which is, of course, positive (see Table I. in his paper). In the case of alloys a positive temperature coefficient for the different samples tested is also given (Table III.), the increased conductivity referred to in the text being for wires cold after heating to the temperature spoken of. The curve which Prof. Wilson draws attention to as being concave downwards is quite in accordance with his tables and statements, as it is evident that it refers to tests upon alloyed wires for the purpose of obtaining the temperature coefficients, which question is obviously apart from annealing. The curve expressing the resistance of copper wire in terms of temperature is known to be concave downwards, and a flatter curve than that for copper, but still concave downwards, would satisfy the figures given in his tables.

I have among the samples of joints, etc., exhibited a piece of wire cut out of a line erected at Foyers over four years ago, and as you will see it has not been in any way affected by exposure to severe weather conditions during that period. The samples which Mr. Kershaw exhibited before the Institution in London some months ago were exposed in a very bad atmosphere vitiated by the fumes from chemical works, under which conditions wires of any other metal than aluminium would also seriously deteriorate. No analyses were given of these samples, and it is probable that they were not of pure aluminium, in which case their corrosion would doubtless be greater.

The welding of aluminium that has been referred to by Mr. Sayers I dismissed in a sentence, not appreciating the necessity of entering fully into details of the simple operation in question. Mr. Bubb having fully explained the method adopted, I need not recapitulate, but can fully endorse his statement to the effect that the process is quite within the scope of the average workman's intelligence. The joint which I have described as having been used for No. 12 S.W.G. telephone wire is necessary so as not to reduce the tensile strength of the wire by annealing a portion actually under stress, as would be the case were a simple weld adopted.

The tensile strength of copper wire, as instanced by Mr. McWhirter, almost exactly corresponds with that taken in the paper when comparing copper with aluminium in Table V. As far as I am aware it is very exceptional practice to run wires of different metals on the same poles, but should this be necessary in special cases the problem of running aluminium wires in conjunction with those of other metals should not—due attention being paid to the design—be more difficult than in the case of pairs of other metals, such as copper and iron.

Mr. Morrison.

I am very much interested to hear from Mr. Mavor of his satisfaction with the aluminium apparatus which he has used for electrical purposes. The figure of £2 per I.H.P. per annum, which he gives as the cost of steam power in a certain locality in the North of England, is certainly surprisingly low and almost incomprehensible. If a 3,000-hour year forms the basis of this figure, it would have to be multiplied by practically three to compare with the figures I have instanced, making, say, £6 per I.H.P. year. If Mr. Mavor means a full 8,760-hour year, I would point out that the most economical steam-engines now in use require the combustion of very nearly four tons of coal per H.P. per annum, working continuously at their highest efficiency. This fixes the price of fuel at a figure which, assuming the price of coal to be the cheapest obtainable, leaves a very slender margin for running charges, maintenance, interest, depreciation, oil, waste, stores, etc. Water-power companies, as I have pointed out, sell power at £4 per electrical horse-power year (delivered on the switch-board of the consumer), which figure pays all the charges enumerated above, and profits to the shareholders in addition. The compressive strength of aluminium which Mr. Mavor asked for is, for pure metal as cast, about six tons; for annealed, five tons; and for forged, seven tons per square inch. For further data as to the mechanical properties of aluminium wires, pure and alloyed, I would refer him to the tables given in Professor Wilson's paper.

In answer to the questions put by Mr. Chamen and some of the other speakers, I would say that for commercial reasons, which they will, no doubt, readily appreciate, it is not possible for me to discuss the points they raise in greater detail.

The Chairman.

The meeting was brought to a close by the CHAIRMAN proposing a vote of thanks to Mr. Murray Morrison, and this was done with acclamation.

CALCUTTA LOCAL SECTION.

SOME HINTS ON OVERHEAD CONSTRUCTION.

By OLDBURY BURNE, Associate.

(*Paper read at Meeting of Section, April 19, 1901.*)

DIP OF COPPER WIRE.

The usual practice is to strain the wire up to such a dip that the tension shall be one-fourth of the breaking strain. For the wire we use in the Indian Telegraph Department which is made on the British Post Office specification; one-fourth breaking strain is given by the formula—

$$S = \frac{\text{Weight per mile} \times 3{\cdot}3}{4} \quad \dots\dots\dots \quad (1)$$

and the dip in feet by the formula—

$$d = \frac{l^2 W}{8 S} \quad \dots\dots\dots\dots\dots \quad (2)$$

Where $S = \frac{1}{4}$ Breaking strain.
$d =$ Dip in feet.
$l =$ Length of span in feet.
$W =$ Weight of 1 foot of wire in lbs. $= {\cdot}0189$ for 100 lbs. wire.

The dips calculated from this formula will be found in the table attached to this paper for spans from 100 to 300 feet. The dip, it will be noticed, increases as the square of the span, and it is the same for every size of wire, as is evident from the formula, when any increase in W the weight of the wire is compensated for by a proportionate increase in S, the strain it will stand. This latter fact is very often overlooked by native workmen, who will almost always strain a light wire tighter than a heavy one unless very carefully watched.

In order that the wire may never be subjected to more than one-fourth breaking strain, it is necessary that the dip should never be less than that given in the table under any condition of temperature. That is to say, the wire must be given such a dip when erected, that with the greatest shrinkage which may ever take place with change of temperature, it shall not be less than that given in the table. Therefore as copper wire shrinks with a fall in temperature, we want the dip to be that given in the table when the wire is at the lowest temperature it is ever likely to be subjected to. The effect of temperature only on copper wire is given by the following formulæ, taken from the article on the subject by Preece in Munro and Jamieson's Pocket Book—

$$L = l + \frac{8\,d^2}{3\,L} \quad \dots\dots\dots\dots\dots \quad (3)$$

$$d' = d\sqrt{\frac{L - l + L\,K\,T}{L - l}} \quad \dots\dots\dots \quad (4)$$

$$S' = S\,\frac{d}{d'} \quad \dots\dots\dots\dots\dots \quad (5)$$

Where l = Span.
L = Length of wire in span.
d = Dip at standard temperature, *i.e.*, min. temp.
d′ = Dip at any other temperature.
S = Strain at minimum temperature.
S′ = Strain at any other temperature.
W = Weight of unit length of wire.
T = Difference of temperature in degrees F.
K = Co-efficient of expansion for copper wire.
= ·00,000,956 per degree F.

The values of d′ & S′ calculated from (4) & (5) will be found set out in the curves (Fig. 1) for wire of 100 lbs. per mile, for spans of 25, 50,

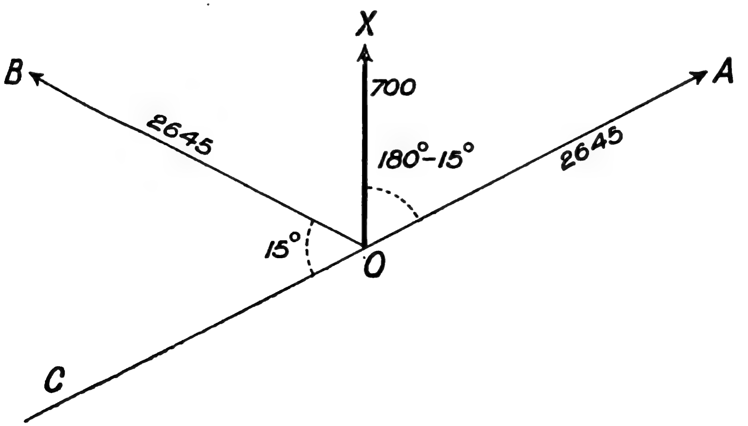


FIG. 1.

75, and 100 yards, for a range of temperature from 100 degrees above that taken as standard to that which would reduce the dip to nothing if the wire did not stretch. The results set out in these curves are at first sight rather startling. It will be noticed that in a span of 100 yards if, after the wire has been erected at the regular dip of 2·58 feet to give one-fourth breaking strain, the temperature falls, a fall of 15¼ degrees reduces the dip to 1·4 feet and increases the tension to one-half breaking strain, and a fall of 19 degrees reduces the dip to ·7 feet and increases the tension to breaking strain. With the shorter spans the effect is still more marked, for in a fifty yards span, a fall of only 4 degrees reduces the dip from ·65 feet to ·3 feet and increases the tension from one-fourth to one-half breaking strain and something less than 5 degrees increases the tension to breaking strain. Of course long before the tension rises to breaking strain the wire will begin to stretch, and the stretching will increase in proportion to the strain, but still the wire will be tried much above its proper working strain, and if the fall in temperature is considerable it will be permanently stretched and not recover itself when the temperature rises again. If it had stretched in this way once or

twice and had then been pulled up again to the tabular dip when the temperature is high, and no allowance is made for it, it may very well happen that the limit of its elasticity may be passed and the wire will break some cold night. The wire which we use in the Telegraph Department is specified to stretch only 1½ per cent. before breaking, so that the elastic limit is soon reached, and we do find pretty often that breaks occur, especially in short spans. In these short spans not only is the effect of temperature very much greater than in the long ones, but a very small error in measuring the dip when erecting the wire is sufficient to make the tension very much greater than it should be. Looking at the curves for a 50 yards span, observe that if the dip is made a little more than 3 inches less than it should be, the tension is raised to half breaking strain, and in a 25 yards span an error of about 1 inch will bring the tension up to breaking strain. In ordinary long spans of 75 yards and over it is usually most convenient and quite accurate enough to strain up wire by measuring the dip at the centre of the span. When this method is employed the correct dip to give the wire for any temperature can be easily got from the dip curves. Suppose we have to strain up a wire with spans 75 yards long in Calcutta in the hot weather where the temperature of the wire may be, say 90 degrees at time of straining. The lowest temperature it will have to stand in the cold weather will be, say 50 degrees. Then we have to allow for a difference of temperature of 40 degrees. Look at the curve of dips for a 75 yards span where it cuts the vertical line corresponding to 40 degrees, and you will find the dip should be just over 36 inches. This dip will allow of its not being tried to more than one-fourth breaking strain if the temperature falls to 50 degrees. In spans of less than 75 yards where small errors in measuring the dip make a very large difference in the tension, it will be better to strain up by using some form of portable dynamometer to measure the strain, and take the value of the proper strain to apply from the curves showing the strains. These curves are plotted for wire weighing 100 lbs. per mile, but can be easily read off for wire of other weights by merely multiplying the value as given by the curve by the weight per mile of the wire divided by 100.

Suppose with the same range of temperature as above, we want to strain up wire weighing 600 lbs. per mile in spans of 50 yards. Then looking at the curve of strains for 50 yards spans where it cuts the line corresponding to 40 degrees, we find the proper strain to be 28 lbs. for 100 lbs. wire, which being multiplied by $\frac{600}{100}$ gives $28 \times 6 = 168$ lbs. as the proper strain for 600 lbs. wire at this temperature. When the lengths of the spans are intermediate between those for which the curves are drawn, the proper values can be quite sufficiently accurately taken off by inspection for practical purposes.

These curves take no account of the elasticity and stretching of the wire with changes in stress and give considerably bigger corrections for the dip than are really necessary, but they are on the safe side and might be worked to without inconvenience for the shorter spans where the dips given are not large enough to cause any danger from the wires getting into contact. Since writing the above a paper by Hopkinson has appeared in the *Electrician* for January 25, 1901, giving a

formula by which dips can be corrected for temperature and elasticity combined, and Mr. M. G. Simpson will, I hope, tell you something of this in the discussion on this paper and also of some very interesting practical experiments carried out by Messrs. Styan and Shields, at Karachi, which agree very nearly with the formula as given by Hopkinson.

Practical Hints on straining up Wire.—To measure a dip the most convenient way is to mark off the required amount from the top of a light bamboo, which should be some 3 or 4 feet shorter than the height of the wire from the ground, and to have another bamboo about 6 feet long. Then have a man at midspan who holds the shorter bamboo on the ground and slides the longer one up and down till a man on one of the posts tells him its top is just in line with the two points of support. He then ties the two bamboos together and the wires are pulled up to the dip mark. If many wires are to be pulled up it is convenient to mark the dip for each wire on the stick. In pulling up long lengths of wire, owing to the friction at the points of support the dip has a tendency to be greater as the span is farther from the point where the strain is applied, if the wire is merely pulled up till it touches the dip mark. The dips will be got more even by pulling the wire a little above the mark and then slacking it down, but in doing this the wire must not be pulled up enough to put more than one-half breaking strain on it at the outside. To ensure this it is well to have another mark above that for the dip curves. The best way to slack out the wire is to slightly untwist the rope stop which holds it, and let it out in jerks of a very little at a time. This is easily done if the straining is done on the ground as it should be, and the jerk seems to ensure the wire running back evenly all along the length strained, which is not the case when the wire is gradually slacked off with the tackle. Both for this reason and because it does not damage the wire, the rope stop generally used in India for gripping the wire is better than any of the many metal vice-like gripping devices which have been brought out.

Binding.—In binding the wires to the insulators it is necessary that the binders should be as tight as possible. If loose they allow a little play of the line wire when it vibrates in the wind, and in a very short time the wire is nearly cut through and breaks. This has been a very common cause of breaks on our telegraph lines. Breaks have also often been caused by little rings of binding wire left on when re-binding and re-levelling old lines. These rings find their way to the centre of the span or to a joint and by constantly vibrating and revolving gradually cut into the wire till it is so much reduced as to break.

To prevent the binding wires cutting into the line wire at the insulators, we now usually warp the latter with a thin strip of copper before binding; this is found to answer well.

Stays.—Wherever it is possible, all posts subjected to lateral strains either at angles or terminals should be stayed so that all lateral strain is counteracted by the stay. It is a very common thing to see stays at terminals put in much too light. In staying terminal posts it has to be

borne in mind that the strain in the stay is always greater than that in the line, and that the ratio between them varies greatly with the angle the stay makes with the ground. The greater the spread of the stay the less strain does it have to bear and it is therefore well to have as great a spread as can be conveniently given. It must also be remembered that with small spreads the stay exerts a large downward pull on the post. The following table gives the strain which a horizontal pull of 1 lb. at the head of a post brings upon a stay at various angles with the ground. The strain in the stay is given by the formula: $P = S \cos D$, where $S =$ strain in the stay, P the strain in the line and D the angle the stay makes with the ground.

Looking at the table, notice that up to $D = 60$ degrees the strain in the stay is less than twice that in the line wire, but that when D is more than 60 degrees the strain in the stay is more than twice that in the line and tends to rise more and more rapidly as D increases. An angle of 60 degrees gives usually a fairly convenient spread, with the distance of the stay from the post slightly more than one-half the height of the post (1·5 : 2); with this angle the stay must be twice as strong as the line wires terminated on the post, and if the stay and line wires are of equal strength, weight for weight, it is necessary to put twice as heavy wires in the stay as in the line.

D = angle of stay with horizontal.	Stress in stay for every lb. of stress in line wires.	D = angle of stay with horizontal.	Stress in stay for every lb. of stress in line wires.
10°	1·02	60°	2·00
20°	1·07	70°	2·92
30°	1·15	80°	5·78
40°	1·31	90°	∞
50°	1·56		

When burying stay anchors, workmen very frequently put them down so that the stay makes a bend at the edge of the hole. When this is so the stay gradually straightens and lengthens in so doing when the ground softens, with the result that the post goes over, sometimes to a dangerous extent.

Supports.—The tubular posts which we use in the Telegraph Department known as the Hamilton's A B C—— series have been found on the whole about the most serviceable kind to use in this country. They are made in 8-foot lengths, to be easy of carriage, and lend themselves readily to being lengthened or shortened as required. Their average life from our experience is well over thirty years. They fail first near the bottom either by rust forming between the inner bands and the tube bursting them or by rust forming between the bottom outer band and the tube bursting off the band. Both these faults may be guarded against by having both outer and inner bands

and the tubes galvanised separately before being put together. When this is done the post will probably last fully forty years. Being made of thin sheet iron they are somewhat easily dented and thereby seriously weakened, it is on this account necessary to protect them at corners and places where carts may run into them, by putting up old sockets or some such thing. They are specified to stand the following horizontal pulls near the top of the various tubes :—A tube, 500 lbs.; B tube, 840 lbs.; C tube, 1,500 lbs.; D tube, 2,400 lbs.; E tube, 3,200 lbs.; F tube, 4,000 lbs.; G tube, 4,800 lbs. If these figures are plotted in a curve it will be seen that the pulls the lower tubes will stand are rather greater than those brought to bear on them by applying the specified strains to the tubes above them. This being so a post will usually break in the top tube, if a strain sufficient to break it be applied at the top. We have never found them to break by crumpling up from the weight of wires on them, so that this factor may be neglected in calculating the number of wires they will carry. They fail first from lateral pressures due to wind. To ascertain therefore the safe load of wires for any line, we have to fix upon the maximum wind pressure that the line is likely to have to resist. This may be fairly safely taken at 30 lbs. per square foot of flat surface, corresponding to a wind velocity of 80 miles per hour approximately. This pressure being for flat surfaces may be multiplied by two-thirds to give the equivalent pressure on the cylindrical surfaces of the wires. An example will probably best show how to determine the size of post required to carry a given number of wires in a line with a given number of posts per mile.

Example.—Wanted the size of post to carry six No. 0 wires on the top three feet of it, where the spans are 225 feet and the maximum wind pressures to be allowed for is 30 lbs. per square foot.

Each post has to carry one span; the sectional area of wires in a span $= 225 \times 6 \times {\cdot}0277 = 37{\cdot}4$ square feet; where ·0277 is the diameter in feet of the wires;

Wind pressure on the wires $= 37{\cdot}4 \times 30 \times \frac{2}{3} = 748$ lbs.;

Our post therefore must be able to stand 748 lbs. applied near the top. A B-tube will stand 840 lbs., which gives hardly enough margin for safety, but a C-tube will stand 1,500 lbs., which gives a factor of safety of 2, which is ample in this case, when the strain allowed for is not likely to be experienced; or if it is, at most only once or twice in the life of the post. We may therefore use a post with the top tube C, adding as many of the series as we like below to get the requisite height; for as above stated the post is not weakened by so doing.

This calculation is of course only rough; but where the wind pressure to be allowed for cannot be accurately known, and the strength of the post may vary from 25 to 50 per cent. above that given in the table, it is quite accurate enough for practical purposes. Any one of an academic turn of mind may amuse himself by taking moments about the ground line for the different wires, and the post itself and equating the sum of them to the moment the post will stand. It may often happen in towns that an angle post, can neither be

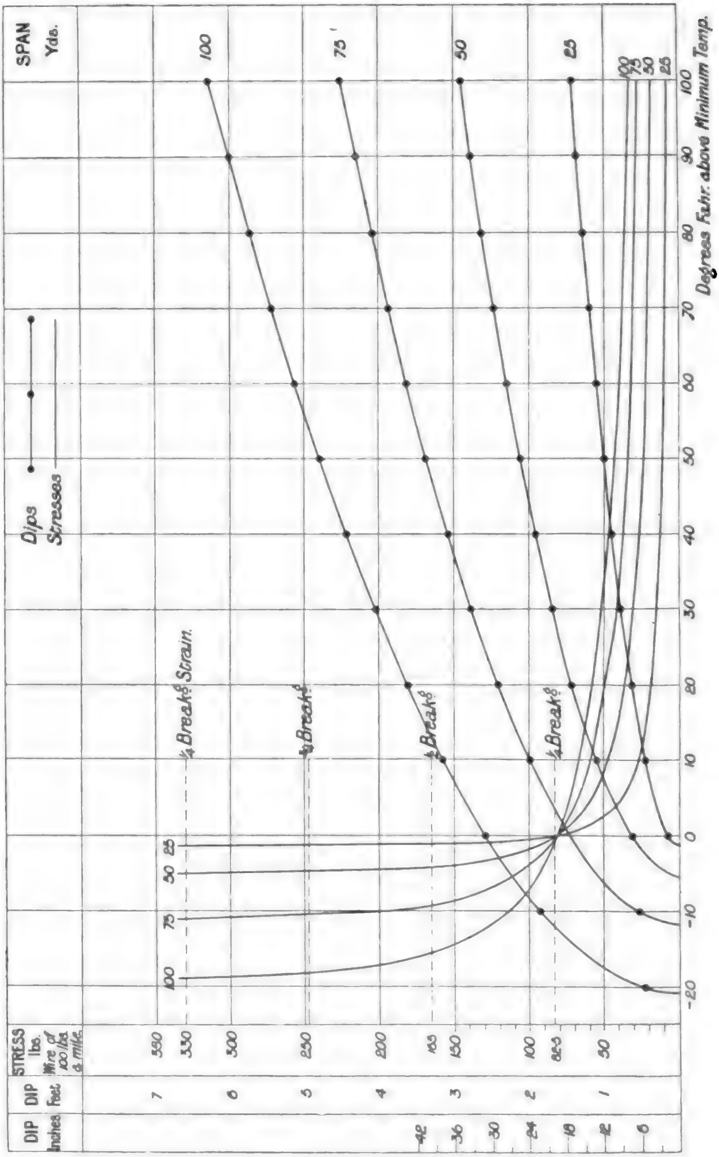


FIG. 2.

stayed or strutted. In that case we want some way of finding what size of post to use to withstand the strain caused by the angle, the following example shows how this may be readily done:—

Example.—Wanted the size of post which will support two No. 0 wires weighing 1,600 lbs. per mile each, without a stay; where the

line makes an angle of 15 degrees with the straight, the wires being at one-fourth breaking strain.

Stress in the line wires $= 1{,}600 \times 2 \times \frac{3 \cdot 3}{4} = 2{,}645$ lbs.; construct a diagram as Fig. 2, where O is the post, OA, OB the directions of the lines, and BOC the angle, the line makes with the straight = 15 degrees in this case. Lay off on OA, OB to scale 2,645, and construct the parallelogram of forces with AX parallel to OB and BX parallel to OA, and get OX the resultant = 700 lbs. roughly.

As this stress is continuous we must allow a factor of safety of four at least and our top tube must stand a breaking strain of $700 \times 4 = 2{,}800$. A D-tube only stands 2,400, so we must use an E, which stands 3,200 lbs., and as before add as many tubes below as are necessary to give the height required.

OX may also be got from—

$$OX = \frac{OA \operatorname{Sin} 15^\circ}{\operatorname{Sin} \frac{180^\circ - 15^\circ}{2}}$$

$$= \frac{2{,}645 \times \cdot 258}{99} = 690 \text{ lbs.}$$

This is more accurate.

TABLE OF DIPS FOR COPPER WIRE.

Made to Post Office Specification.

Span. Feet.	Dip. Feet.	Dip. Inches.	Span. Feet.	Dip. Feet.	Dip. Inches.
100	·287	3·45	210	1·265	15·2
110	·347	4·16	220	1·390	16·6
120	·414	4·95	230	1·52	18·2
130	·485	5·82	240	1·65	20·0
140	·561	6·75	250	1·79	21·5
150	·646	7·75	260	1·94	23·3
160	·734	8·85	270	2·09	25·1
170	·830	10·0	280	2·25	27·0
180	·930	11·2	290	2·41	29·0
190	1·035	12·4	300	2·58	31·0
200	1·145	13·8			

Rev. Father Lafont.

The Rev. Father LAFONT: I should like to ask how the temperature of the wire is taken. I think, the air temperature will be too low, as a metal exposed to the sun may reach very high temperatures indeed, and if the wires be stretched when at these temperatures, the dip at night, for instance, may be considerably below the standard. A contact thermometer might be used, or better still the resistance of the hot wire might be tested to determine the temperature. I should like to know, in the cases of wires breaking when covered with snow or ice, if any measurements have been taken to ascertain how much of the stress was due to contraction by cold and how much to the extra weight of water. The latter cause, I think, will be found smaller than the first.

Mr. Meares.

Mr. J. W. MEARES: The paper is one of the greatest interest in India where the use of aërial lines tends to become almost universal. I am afraid we mostly work more by rule of thumb than we ought to, possibly from the comparative scarcity of information to be obtained on the subject, though to our telegraph friends it is all A B C.

One would expect the temperature of copper wire, when erected in the sun, to be nearer 150° than 90°. Reflection must account for the small rise noticed, and in the case of iron telegraph wires one would expect this to be almost absent, for certainly ironwork left in the sun becomes unbearably hot. The dip-stick method would appear to be applicable only to the plains; in the hills one would often need a bamboo several hundred feet long. I did not notice either dip-sticks or dynamometers in use in Calcutta when the electric light wires were put up, but the result has been, on the whole, very satisfactory. As bearing on the rusting of Hamilton's tubes on the inside, I may mention the similar case of open drains for water-power work. If galvanised after bending they last well, but to bend a piece already galvanised results in stripping or flaking off the zinc. It would seem advisable to galvanise all parts of these tubes inside and out, otherwise in galvanising the completed tube the inside surfaces will suffer from excess of pickle and lack of zinc.

I notice that a factor of safety of two in one case and of four in another has been assumed; the Board of Trade Rules, in force here as the Calcutta Electric Lighting Regulations, insist on a factor of safety "for aërial lines at least 6, and for all other parts of the structure at least 12, taking the maximum possible wind pressure at 50 lbs. per square foot," which makes the condition of electric lighting somewhat different from those of telegraph construction.

Mr. Simpson.

Mr. M. G. SIMPSON: The subject of this paper is one of peculiar importance in India, where so far as one can see at present power distribution will be largely done through overhead conductors, and the warning given on the subject of temperature is one we should all do well to remember. By combining the two equations (3) and (4) and eliminating L we get $d' = \sqrt{d^2 + (\frac{3}{8} l^2 + d^2) KT}$. The last term under the root is so small we may neglect it and we have left $d' = \sqrt{d^2 + \frac{3}{8} KTl^2}$. This is an easy formula from which to draw the curves given by the author. But as it has been pointed out these

curves do not represent the facts in so far as they take no account of elasticity. This was recognised by Messrs. Styan and Shields of the Telegraph Department in Karachi, who attacked the problem from the Mr. Simpson.

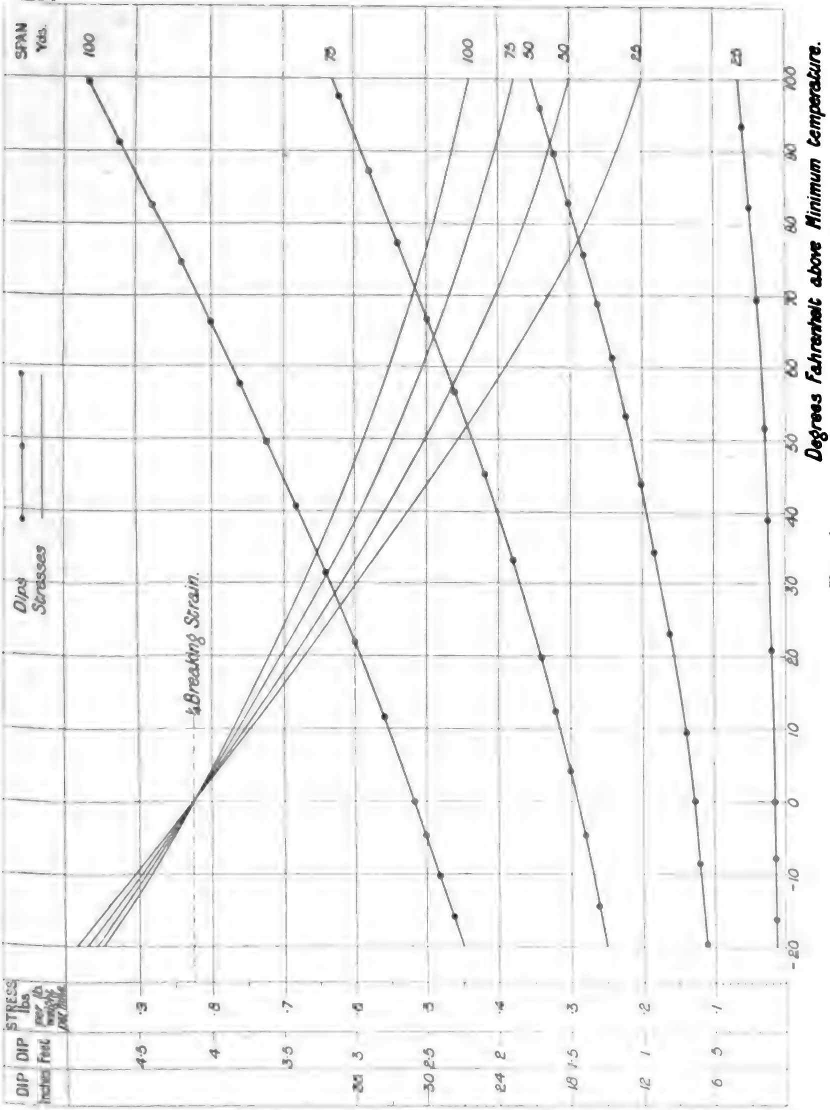


FIG. A.

experimental side by erecting a span of 220 feet of copper wire with which they conducted a very careful set of experiments, the results of which were in close agreement with the mathematical solution of the problem as given by Mr. B. Hopkinson in the *Electrician* of January 25, 1901. Following Mr. Hopkinson's method I have drawn curves (Fig. A)

Mr. Simpson.

for the same spans as the author, taking elasticity into account. On comparing these two sets of curves we see that the effect of elasticity is to flatten the curves and that for moderate changes of temperature the difference in strain is not very great after all. The short spans suffer more, but not so very much more, than the longer ones. Unless I have made an error in my calculation it would require a fall of over 100° F. to increase the strain in a span of 25 yards from one-fourth to one-half breaking strain.

It remains to be settled how to find out approximately the temperature of the wire at the time of erection, if exposed to the sun's rays. Some rough experiments made in Calcutta a few weeks ago showed it to be from 10° to 20° F. above the shade temperature. It is certainly far below the sun temperature as usually recorded on a thermometer in vacuo, where cooling can only be effected by radiation. In the case of a wire in the air, however, cooling is effected both by radiation and by means of convection, the latter process being greatly quickened in the presence of a wind. Size, too, is a factor to be taken into account; a post is often so hot that it cannot be comfortably touched, but a suspended wire can always be held without discomfort. Probably the temperature of the wire can be got at sufficiently nearly by hanging an ordinary chemical thermometer in the sun.

In the last paragraph of the paper, the formula admits of some simplification. We may write $OX = 2\,OA \sin\frac{15}{2}$ or generally, if t = tension of the wires, and θ = supplement of angle contained by the wires, the resultant tension T is given by $T = 2t \sin\frac{\theta}{2}$.

Mr. Kenyon.

MR. E. A. KENYON: Mr. Burne takes the maximum and minimum temperature in Calcutta as 90° F. and 50° F. respectively, and discusses the dip to be given to wire to allow of contraction and expansion between those limits, but the maximum should, I think, certainly be taken as the maximum in the sun, not in the shade, and this varies probably on ordinary clear days from about 120° F. in the cold weather to about 160° or 170° in the hot, so that the range of temperature to be allowed for is some 110° or 120° in Calcutta, and as much as 150° or more in other parts of India.

Generally speaking our wires have probably been erected at a temperature of 130° or 140° F., and the minimum temperature to which they are subjected might be taken as 40°. The wires have been erected at a quarter breaking strain and the dips at the minimum temperature would therefore work out to 100 yards span, 1 ft.; 75 yards, 0·4 ft.; 50 yards, 0·13 ft.; 25 yards, 0·017 ft. These figures, while bad enough, are considerably less alarming than Mr. Burne's, and go to show that at any rate on 100 yards and 75 yards spans copper wire can be pulled up to one-fourth breaking strain and stand a range of temperature of 100° without fear of breaking. But they also prove that on spans much shorter than 75 yards it cannot safely be pulled up so tight.

Copper wire gives trouble in many ways, but as long as the wire is sound I do not believe we have much reason to fear the effect of tem-

perature, and, speaking from considerable experience, I believe we may perfectly safely put copper wire on to the same posts as iron wire and pull it up to one-fourth breaking strain as we always have hitherto done. But when once up, at whatever dip, it is not safe to re-strain it. The breaks that occur in copper wire are in my experience due chiefly to (1) scratches or cuts in the wire; (2) to the wire wearing away under the binder; and (3) to a cold night at spots where the wire, after being up some years, has lately been re-strained, in which case it probably breaks at some point where it had formerly been bound to an insulator. Mr. Kenyon.

I have never used a dip-stick; I much prefer taking the wire off an intermediate post and measuring the dip between the insulator and the wire, which should be four times the dip in a single span. This is simpler and more accurate than using a stick. With copper wire, however, a dynamometer should always be used, with care to avoid jerks or excessive strain.

It may be of interest to give the results of some tests I made to ascertain whether copper wire deteriorates with age. Eight pieces of wire were cut out of two working wires of 200 lbs. and 300 lbs. per mile, four from each. The 200 lbs. wire had been up twelve years, the 300 lbs. wire six years. The average breaking strain of the 200 lbs. wire was 555 lbs. as against 650 lbs. when new, and of the 300 lbs. wire 787 lbs. as against 950 lbs. when new.

Mr. G. T. W. OLVER: In regard to the question of temperatures, quoted on page 421, it would seem that the author means temperature "in the shade," whereas it is obvious that it is the "sun temperature" which is required. I understand that in the Bombay Presidency the range of temperature during the year may be taken as 130° F. (170°–40°), and if a copper wire of fifty yards' span be subjected to this range the result would be terrible to think of, as we are told that a fall of 5 degrees would raise the tension to the breaking stress. Yet we know that copper wire does stand these large ranges. We must therefore conclude either that there is some factor not dealt with by the equation devised by Sir W. H. Preece, or that the wire must stretch enormously. There can be no doubt that the rope stop used in straining wires is far superior to any metal vice or clip, as no damage is done to the wire. It is known that the strength of hard-drawn copper wire is seriously impaired if the wire be cut or nicked, but so far we have no satisfactory pliers that would prevent such damage. I have been experimenting with different kinds of wood in trying to devise some form of wooden pliers, and after many attempts I have now succeeded. The principal difficulty was met with in preventing the wood from splitting where the pin passes through the two halves. This has now been overcome in a very simple manner, and the wooden pliers are now being adopted. Mr. Olver.

The method of binding recently adopted, viz., using thick strip under the binder and flattening the ends of the binder, is undoubtedly a great improvement, as I have found a very large number of faults caused by the copper wire breaking under the binder at the insulator. The strip must, however, be bound tightly, or the line wire will run through it when it breaks in a span.

I have found that in towns where neither an ordinary stay nor strut

Mr. Olver. can be fitted a strutted stay can invariably be fitted to the base of the post and a strut fitted to the post at a suitable height. Unless this be done the post will bend over with the strain of the wires long before the breaking strain is reached, and the post is not only unsightly, but the insulators are liable to slip out of the brackets.

The heading of the table is not clear, as it is not stated at what temperature the line is erected.

Mr. Shields. Mr. J. C. SHIELDS (*communicated*): In his very interesting paper the author has been good enough to mention some experiments made by Mr. H. S. Styan and myself regarding the elasticity of spans of wire. Some remarks on these experiments and the results arrived at may be of interest. Our attention was first drawn to the matter owing to the divergence which appeared to exist between the effects which, according to the usually accepted formulæ, occur when the temperature of a span of wire is lowered, and the effects which actually occur in practice. It was known that the elasticity of wires (although acknowledged to be considerable) had not been taken into account in the formula called (4) in the author's paper, and we therefore determined to investigate the matter. Certain results which we calculated by taking the ordinary modulus of elasticity given in books appeared to make so startling a difference in the results obtained from this ordinary formula, that we at once came to the conclusion that something must be wrong either with our calculations or the modulus of elasticity. Experiments made later, however, showed that our results were not so far out after all. These experiments were made with a view to determining what length of wire it was necessary actually to withdraw from a span in order to reduce the dip by any given amount. As an example of the results obtained, some average figures for 220 and 50 feet spans of three of the samples of copper wire we tested are given in the subjoined table (p. 434). By dividing the figures in columns 6 and 7 by the temperature co-efficient of expansion multiplied by the length of the span in feet, the number of degrees decrease of temperature which would be required to reduce the dip from 30 to 10 inches, or any of the intermediate dips given, can be worked out. It will be observed that the actual amount of withdrawal necessary to reduce the dip in a 220 feet span from 30 to 24 inches is 0·057 feet, or a little more than double the amount (·028 feet) which is due to the flattening of the catenary. It will therefore actually take a decrease of temperature to effect this change in dip a little more than double that which formula (4) of the author's paper would lead one to expect. As the dip decreases the difference becomes more and more marked. Thus, to decrease the dip from 30 to 10 inches actually requires a withdrawal of about ·303 of a foot, whereas the difference in length of the two catenaries is only ·068 feet, or less than a fourth of the above. To decrease the dip of a 220 feet span from 30 to 10 inches would therefore actually require a decrease of temperature about 4½ times as great as the ordinary formula would lead one to expect.

The effect of elasticity in fairly slack spans (of ordinary lengths in use) is therefore sufficiently large to greatly modify the effect usually supposed to be produced by a change of temperature, and when the dip gets small it is so great as almost entirely to obscure such effect as

Mr. Shields.

would be produced if the only slack available were that which would result from the flattening of the catenary. This latter point is well illustrated by the figures given for the 50 feet span. Suppose such a span is erected at 90° F., and is not to be strained to more than one-third breaking strain when the temperature falls to 40° F., then, according to formula (4) of the author's paper, the dip should be ·66 feet. This dip corresponds to a dip of about 13 feet in a 220 feet span and 24 feet in a 100 yard span, which dips are inconveniently large. From the attached table it will be seen that if the wire is erected at a dip of ·9 inches (corresponding to a dip of 20 inches in a 220 feet span), its elastic elongation by the time the dip has been reduced to ·45 inches (corresponding to 12 inches on a 220 feet span) will amount to $\cdot039 - \cdot012 = \cdot027$ feet; dividing this by $\cdot00{,}000{,}956 \times 50$, we get the number of degrees required to produce such an alteration in length. This works out as 57°, so that the dip of ·9 inches is really more than enough. The result of the wire being elastic is therefore very far from inappreciable, and should not, I think, be neglected. If it is, an effect is neglected which in ordinary spans on which copper wires are used has much more bearing on the result produced by a change of temperature than all the other considerations usually taken into account. The matter is not merely one of sentiment, but bears very materially on the carrying capacity of posts. Moreover, the tighter the wires are put up the better they look. The effect also is one which can easily be allowed for, as I think a little consideration of the matter will show. It is easier, however, to work backwards; assume a given alteration in dip, and then calculate the temperature which would be required to effect such a change. A few figures obtained in this way will enable a curve to be plotted, from which any desired change can be at once read off. First, calculate the length of the catenary at each dip from the ordinary formula; take the difference, and divide by the temperature co-efficient multiplied by the length of the span. Call this result "*t*." This will give the number of degrees which, according to the ordinary formula, would be required to effect the change, but to this must be added the number of degrees required to counterbalance the elastic elongation. This is a very simple matter. When a span of wire is drawn up from one dip to another a definite increase in tension is caused, which can easily be calculated if not already known. Now the elastic elongation is proportional to the stress, so the amount thereof can be obtained by multiplying the increase in stress by a constant. This constant for 100 lbs. copper wire is given in the table, namely, ·0,000,114 feet per foot per pound. The matter can further be simplified when it is remembered that the effect produced by temperature is, like the elastic elongation, proportional to the length of wire. If, therefore, 1 degree decrease of temperature causes a shortening of ·00,000,956 feet it will increase the tension by $\frac{\cdot00{,}000{,}956}{\cdot0{,}000{,}114} = \cdot84$ lbs. This is irrespective of the length, so that, for any span, to the "*t*" obtained above, add $\cdot84\,(s'\text{-}s)$; the sum will be the total number of degrees of temperature required to effect the given change in dip. The result may be set out in a formula as follows:—

Mr. Shields.

Tension in lbs. for wire 100 lbs. per mile.	Observed Dip.		Observed length of wire which on necessary tension being applied come out of span when dip decreased.		Same figures as in last two columns corrected from curves so as to eliminate zero errors.		Calculated length of wire which should come out of span owing to flattening of catenary.		Amount of wire recovered due to elasticity only elastic extension.		Elastic extension per foot.		Elastic Extension per foot per pound $= \frac{E+F}{2} \div$ increase in tension.	
	In 200′ span.	In 50′ span.	In 220′ span.	In 50′ span.	220′ span. = A.	50′ span = B.	220′ span = a.	50′ span = b.	In 220′ span = A-a = C.	In 50′ span = B-b = D	In 220′ span $\frac{C}{220}$ = E	In 50′ span $\frac{D}{50}$ = F		
1	2	3	4	5	6	7	8	9	10	11	12	13		
45	30″	1·4″	...	...	...	...	...	...	...	...	...	...	...	
56	24″	1·1″	0·061′	0·009′	·057	·006	·028	·000	·029	·006	·00013	·00012	·0000114	Whence average extension per foot per pound = ·0000114′ for 100 lbs. copper wire.
69	20″	0·9″	0·103′	0·015′	·100	·012	·043	·000	·057	·012	·00026	·00024	·0000104	
76	18″	0·75″	0·127′	0·019′	·132	·018	·049	·000	·083	·018	·00038	·00036	·0000119	
86	16″	0·65″	0·156′	0·025′	·156	·023	·054	·000	·102	·023	·00046	·00046	·0000112	
98	14″	0·55″	0·191′	0·034′	·195	·030	·059	·000	·136	·030	·00062	·00060	·0000115	
114	12″	0·45″	0·239′	0·042′	·237	·039	·064	·000	·173	·039	·00079	·00078	·0000114	
137	10″	0·35″	0·301′	0·053′	·303	·053	·068	·000	·235	·053	·00107	·00106	·0000115	

Mr. Shields.

$$T = \frac{(s'-s)}{a} + \frac{8\,(d'^2 - d^2)}{3\,Kl^2} \text{ where "} a \text{" is a constant.}$$

$$= \text{for H. D. copper wire } \cdot 84 \times \frac{\text{weight of wire per mile.}}{100}$$

$$= \text{for iron wire } 1 \times \frac{\text{weight of wire per mile.}}{100}$$

All other letters are same as in the paper.

It is interesting to note that the modulus of elasticity worked out from figures given herein, agrees closely with the modulus for drawn copper wire given in Sir William Thomson's article on Elasticity in the *Encyclopedia Britannica.* The modulus given therein is 1,245 to 1,254 × 10^6 grammes per square centimetre or about 17·7 to 17·85 million pounds per square inch. Now a tension of 1 lb. on 100 lbs. copper wire $= \frac{1}{\cdot 0049} = 204{\cdot}1$ lbs. per square inch. Such a stress it has been shown produces an elongation per foot of ·0,000,114 feet; so that the modulus would be $\frac{204{\cdot}1}{\cdot 0{,}000{,}114} = 17{\cdot}92$ million pounds per square inch. Similarly some samples of iron wire tested showed that 100 lbs. iron wire stretches ·0,000,068 feet per foot per lb. The modulus for such a wire would be $= \frac{1}{\cdot 0{,}000{,}068 \times \cdot 00{,}567} = 26$ million lbs. per square inch. Sir William Thomson gives the modulus for iron wire (common) as 26·45 million pounds. It will therefore, I think, be quite sufficiently accurate and safe to take ordinary modulus of elasticity given in books, if it is desired to work out figures for spans of wire of any other metal than iron or H. D. copper telegraph wire. In all these calculations the length of wire in the span has been taken as equal to the distance between the supports, as the error produced by doing this is quite inappreciable for the spans of wire dealt with.

I would conclude these remarks by saying that I think tension dynamometers are faster to work with, safer, and superior in every way to dip-sticks; and I hope they will be more generally adopted in India. Stresses are much more convenient to work with than dips; the difference required to compensate for temperature, for the different spans in ordinary use, works out to be small; and a system of stresses which will be safe for all usual spans can easily be arrived at if desired. The whole matter is one in which I am much interested, and I must thank the author for bringing it forward.

Mr. Scott-Moncrieff.

Mr. K. A. Scott-Moncrieff: I have been impressed with the extreme care exercised by the Telegraph Department in handling copper wires, and I believe that a good deal of this is necessary, because of the stringent requirement of the specification to which these wires have to conform. I am sorry that Mr. Burne has not included this specification in this paper to-night. The high conductivity and great tensile strength required under this specification, make it necessary for the makers to draw the wire with a soft inside and a thin coating of flint-hard copper on the outside. The result of this is that, any damage done to the outside of the wires is done to the only strong portion, and therefore seriously affects the tensile strength. The smallest wire I

Mr. Scott-Moncrieff. have used is No. 12, weighing about 160 lbs. per mile, and although this wire is often very badly used in erection, I have had no breakages. I would therefore like to know if Mr. Burne has experienced as much breakage amongst his 300 lbs. wires as he has with the lighter ones.

I question whether the dynamometers shown to-night can be accurately used where the distance between terminals is short. The native linesman makes off on the slack end of the wire, and in that way may let enough slack into the span to alter the tension considerably. Any slight movement of the head of the post would have the same effect. I have tried to get my men to use the linesman's vice, but have gone back to the rope stop and block and tackle.

I am sorry we have no figures as to the crushing strain that the posts will bear. Mr. Burne has based many of his calculations on the use of No. 0 wire, which is certainly not a telegraph wire, and I think that although in telegraph work the crushing load may be neglected, it becomes an important factor when we put up, say 9, No. 0 wires on a single line of posts. I wish to ask Mr. Burne if he has any knowledge from experience of the lasting properties of these tubular posts when made of mild steel.

Another point which interests me very much is that of factors of safety. The Telegraph Department use the factor 4 in all cases, but the Electric Lighting Regulations require a factor of 6 for the wire and 12 for other parts of the structure. I do not think that 4 is enough for electric supply work where the lines are all in towns, and the consequence of a line coming down may be serious, but I think 6 is high enough for all purposes.

Mr Burne. Mr. O. BURNE (*reply*) *to Mr. Kenyon.*—The maximum temperature mentioned in my example in Calcutta is that which the wire would be likely to have at the time of erection. It might, of course, be much higher than 90° in the middle of the day. The wire when new and bright will probably rarely be above 120° in Calcutta. I do not understand how Mr. Kenyon derives his dips for the various spans. If the temperature falls 100° after wires have been erected at one-fourth breaking strain, the dips would be reduced to zero if the wire did not stretch. Breaks are no doubt often due to scratches and accidental injury, but when the wire is too tight it naturally goes first at the places weakened by such injuries, and would in many cases not go at all if proper allowance were made for temperature when straining up. Mr. Kenyon's method of measuring dip is only good when the ground is level for two spans.

To Father Lafont.—For practical purposes the temperature of the wire would be pretty nearly given by an ordinary thermometer exposed to the sun. The temperature of the wire will vary slightly with its brightness or dulness. A thermometer wrapped in a helix of the wire itself would probably give the nearest result. Snow and ice are known to collect on wires both in England and Kashmere in sufficient quantities to break the wire by their weight alone. The wires in Kashmere have been coated with ice and snow to a diameter of about 4 inches.

To Mr. Simpson.—The curves as given by Mr. Simpson which take the elasticity into account are better to work to than those given by me,

which only show the effect of temperature. The difference becomes very marked at the low temperatures, but not very great over the practical range of temperatures. The latter curves show, however, very clearly how much more necessary an allowance for temperature is in short than in long spans. Mr. Burne.

To Mr. Meares.—The temperature of wire which is almost unbearable to the hand will not be much more than 120° to 130°. The dip-stick cannot, of course, but the dynamometer can, with great advantage, be used in the Hills. With regard to galvanising; we find that putting the posts into an alkaline bath after galvanising kills off most of the pickle and posts thus treated last well, even without the surfaces under the bands, and in seams, being galvanised. The regulations mentioned by Mr. Meares are, I think, well on the safe side, as they should be especially for light and power wires in towns, but I very much doubt if they are worked up to, or anything like worked up to.

To Mr. Scott-Moncrieff.—Our wire is undoubtedly very liable to damage on account of its strength lying so much in its skin. We should do well, I think, to use a softer wire which would stand more rough usage. I am unable to say if there is any connection between the size of the wire and the number of breaks. The dynamometers can, I think, be used so as to get the dip accurately by skilled men, such as we employ for the purpose. The size of post which would be necessary to stand the wind pressure, for 9 No. 0 wires would be in no danger of being crushed by their weight. I regret I have no experience of the lasting properties of mild steel posts, but am inclined to think that rust once started would eat into them more rapidly than iron ones.

To Mr. Olver.—The temperature referred to is that of the wire. Sir W. H. Preece's formula does not take account of the stretching of the wire, as will be found stated in Munro and Jamieson's Pocket Book where the formula is given. The experiments made by Messrs. Styan and Shields came to my knowledge when writing my paper, they were so carefully carried out and entailed so much labour that I did not think any experiments I should have time to make would be of equal value. They will, I hope, give us a paper on the subject themselves. With the protecting strip of copper now used under the binder I do not think there is any need for wooden pliers or tools for binding, as the binder itself is soft and not easily damaged. The binder with flattened ends is, I think, always liable to come loose; I should prefer the ordinary round binder which takes a much better hold. With regard to the table I do not see Mr. Olver's difficulty. On page 420 of my paper it is stated that the dips given in the table are those the wire is to have when it is at its lowest temperature. It is, of course not possible to say what this may be, except for special cases.

ORIGINAL COMMUNICATION.

THE LIMITATIONS OF GRAPHICAL METHODS IN ELECTRICAL THEORY.

By ALEXANDER RUSSELL, M.A., Member.

It is well known that when the potential differences and the currents in an alternating-current network follow the harmonic law, then their effective values and phase differences can be represented by the lengths and inclinations to one another of lines drawn in a plane. When they do not follow this law this can only be done in a few special cases. Seeing that in practice the assumption of a sine law is rarely justified, it is of importance to investigate mathematically in what cases we can use graphical methods, and in what cases they fail to represent the effective values and the phase differences of the various electrical quantities involved.

The phase difference ($\alpha_{1 \cdot 2}$) between two periodic quantities e_1 and e_2 of the same frequency is defined by the equation—

$$\cos \alpha_{1 \cdot 2} = \frac{\int_0^T e_1 e_2 \, dt}{\left\{ \int_0^T e_1^2 \, dt \int_0^T e_2^2 \, dt \right\}^{\frac{1}{2}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)^*$$

The limitation is also made that the angle $\alpha_{1 \cdot 2}$ is an angle lying between 0 deg. and 180 deg. In this definition T is the period of a complete cycle, and t is the time in seconds from the era of reckoning.

It follows from (1) that if either e_1 or e_2 is constant, then $\cos \alpha_{1 \cdot 2}$ is zero, and therefore $\alpha_{1 \cdot 2}$ is 90 degrees. We must therefore represent the effective values of a constant quantity and a periodic function by two lines drawn at right angles to one another. The effective value of their sum is represented in magnitude and phase by the diagonal of the rectangle constructed on these lines as adjacent sides. Similarly, when both e_1 and e_2 are variable, the ordinary parallelogram construction will give the effective value of their sum. When, however, we have three periodic quantities of the same frequency, then not only is the assumption that their effective values can be represented in magnitude and phase by lines drawn in one plane unjustifiable, but it is necessary to prove that they can be represented by lines drawn in space. This can be done as follows :—

Let x, y and z be the three periodic functions, and let α, β and γ be the angles of phase difference between y and z, z and x, and x and y respectively. If α, β and γ can always form a solid angle, then $\alpha + \beta + \gamma$ must not be greater than four right angles, and also no two of the angles must be greater than the third.

* See *The Electrician*, vol. 44, p. 49.

From the definition of phase difference we have—

$$\cos a = \frac{\int_0^T y z \, dt}{\left\{ \int_0^T y^2 \, dt \int_0^T z^2 \, dt \right\}^{\frac{1}{2}}}$$

Divide the period T into a large number (n) of equal intervals, and let $x_1, x_2, \ldots x_n$; $y_1, y_2, \ldots y_n$; $z_1, z_2, \ldots z_n$ be the values of the functions at the end of each of these intervals.

Then from the meaning of integration we have—

$$\cos^2 a = \frac{(y_1 z_1 + y_2 z_2 + \ldots + y_n z_n)^2}{(y_1^2 + y_2^2 + \ldots + y_n^2)(z_1^2 + z_2^2 + \ldots + z_n^2)}$$

with corresponding values for $\cos^2\beta$ and $\cos^2\gamma$.

$$\begin{aligned} \text{Let } X &= x_1^2 + x_2^2 + \ldots + x_n^2 & A &= y_1 z_1 + y_2 z_2 + \ldots + y_n z_n \\ Y &= y_1^2 + y_2^2 + \ldots + y_n^2 & B &= z_1 x_1 + z_2 x_2 + \ldots + z_n x_n \\ Z &= z_1^2 + z_2^2 + \ldots + z_n^2 & C &= x_1 y_1 + x_2 y_2 + \ldots + x_n y_n \end{aligned}$$

Then—

$$1 - \cos^2 a - \cos^2\beta - \cos^2\gamma + 2\cos a \cos\beta\cos\gamma$$
$$= \frac{XYZ - XA^2 - YB^2 - ZC^2 + 2ABC}{XYZ} \quad \ldots \quad (a)$$

Now—

$$X(XYZ - XA^2 - YB^2 - ZC^2 + 2ABC)$$
$$= (XY - C^2)(XZ - B^2) - (XA - CB)^2$$

Also—

$$XY - C^2 = (x_1 y_2 - x_2 y_1)^2 + (x_1 y_3 - x_3 y_1)^2 + \ldots \quad (b)$$
$$XZ - B^2 = (x_1 z_2 - x_2 z_1)^2 + (x_1 z_3 - x_3 z_1)^2 + \ldots \quad (c)$$
$$XA - CB = (x_1 y_2 - x_2 y_1)(x_1 z_2 - x_2 z_1)$$
$$+ (x_1 y_3 - x_3 y_1)(x_1 z_3 - x_3 z_1) + \ldots \quad (d)$$

Now it is easy to show that

$(x^2 + y^2 + \ldots)(a^2 + b^2 + \ldots)$ is not less than $(xa + yb + \ldots)^2$. It therefore follows from (b) (c) and (d) that $(XY - c^2)(XZ - B^2) - (XA - CB)^2$ equals zero or a positive quantity. Hence from (a)—

$1 - \cos^2 a - \cos^2\beta - \cos^2\gamma + 2\cos a\cos\beta\cos\gamma = 0$ or a positive quantity. Now the trigonometrical expression can be written in the form

$$\left\{\cos\gamma - \cos(a + \beta)\right\}\left\{\cos(a - \beta) - \cos\gamma\right\}.$$

Hence we see that if it vanishes, the sum of two of the angles equals the third or the sum of the three equals four right angles. The three vectors in this case are therefore in one plane.

It may also be written in the form—

$$4\sin\frac{a+\beta+\gamma}{2}\sin\frac{\beta+\gamma-a}{2}\sin\frac{\gamma+a-\beta}{2}\sin\frac{a+\beta-\gamma}{2} \ldots (e).$$

By hypothesis, a, β and γ lie between 0 deg. and 180 deg. As the expression (e) is positive, all the terms may be positive, or two of them may be negative, or all four of them may be negative.

If they are all positive, then $a + \beta + \gamma$ is less than four right angles,

and also any two of the angles are together greater than the third. Suppose, now, that the first two terms of (e) are negative. Then $\alpha+\beta+\gamma$ is greater than 2π, and $\alpha-\beta-\gamma$ is greater than zero. Therefore α is greater than π, which is contrary to the hypothesis. Similarly, no other two terms can be negative and *a fortiori* the whole four cannot be negative. In all cases, therefore, we see that the sum of the three angles is not greater than four right angles, and that the sum of two of them is never greater than the third. Hence the three angles can always form a solid angle.

We shall apply the above theorem to find graphically the effective value of the sum of three alternating periodic functions. Let e_2, e_3 and e_4 be the three functions, and let e_1 be their resultant, then

$$e_1 = e_2 + e_3 + e_4.$$

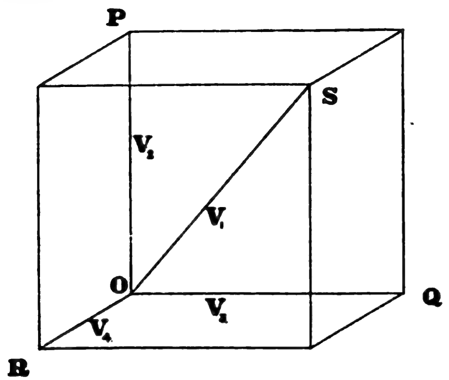
Hence

$$\left.\begin{aligned} V_1 &= V_2 \cos \alpha_{1\cdot 2} + V_3 \cos \alpha_{1\cdot 3} + V_4 \cos \alpha_{1\cdot 4} \\ V_1 \cos \alpha_{1\cdot 2} &= V_2 + V_3 \cos \alpha_{2\cdot 3} + V_4 \cos \alpha_{2\cdot 4} \\ V_1 \cos \alpha_{1\cdot 3} &= V_2 \cos \alpha_{2\cdot 3} + V_3 + V_4 \cos \alpha_{3\cdot 4} \\ V_1 \cos \alpha_{1\cdot 4} &= V_2 \cos \alpha_{2\cdot 4} + V_3 \cos \alpha_{3\cdot 4} + V_4 \end{aligned}\right\} \quad . \quad . \quad . \quad (a)$$

And

$$V_1^2 = V_2^2 + V_3^2 + V_4^2 + 2\,V_3 V_4 \cos \alpha_{3\cdot 4} + 2\,V_4 V_2 \cos \alpha_{2\cdot 4} + 2\,V_2 V_3 \cos \alpha_{2\cdot 3} \quad . \quad . \quad . \quad (b)$$

In these equations V_n is the effective value of e_n and $\alpha_{n\cdot m}$ is the phase difference between e_n and e_m.



Construct the solid angle at O (see fig.), so that the angles P O Q, Q O R and R O P equal $\alpha_{2\cdot 3}$, $\alpha_{3\cdot 4}$ and $\alpha_{4\cdot 2}$ respectively. Complete the parallelopiped O P Q R S and let O S be the diagonal. Then from (b) we see that O S equals V_1. Hence from the equations (a) we see that the angles P O S, Q O S and R O S equal $\alpha_{1\cdot 2}$, $\alpha_{1\cdot 3}$ and $\alpha_{1\cdot 4}$ respectively. We can thus extend graphical methods to solid geometry for the case of three variable quantities.[1]

In this case we can show from equations (a) that

$$\frac{V_1}{\sin(\alpha_{2\cdot 3}, \alpha_{2\cdot 4}, \alpha_{3\cdot 4})} = \frac{V_2}{\sin(\alpha_{1\cdot 3}, \alpha_{1\cdot 4}, \alpha_{3\cdot 4})} = \frac{V_3}{\sin(\alpha_{1\cdot 2}, \alpha_{1\cdot 4}, \alpha_{2\cdot 4})} = \frac{V_4}{\sin(\alpha_{1\cdot 2}, \alpha_{1\cdot 3}, \alpha_{2\cdot 3})}$$

where $\sin(\alpha, \beta, \gamma) = \left\{1 - \cos^2\alpha - \cos^2\beta - \cos^2\gamma + 2\cos\alpha\cos\beta\cos\gamma\right\}^{\frac{1}{2}}$

[1] See *The Electrician*, vol. 38, p. 805.

In the general case it is not possible to represent four periodic quantities of the same frequency by lines drawn in space. For example, suppose one of them is constant, then it would have to be represented by a line drawn at right angles to the other three, which is impossible when they form a solid angle.

It is customary in electro-technical theory to assume that any number of vectors can be drawn in one plane, and so results are arrived at which are sometimes very far from being correct when we are dealing with E.M.F. and current waves which are not sine-shaped. It is easy to give illustrations.

For example, it is frequently stated that the locus of the extremity of the vector representing the primary current in an air-core transformer is a semi-circle if we can neglect the resistance of the primary coil. Again a graphical proof is frequently given that a wattmeter which has been calibrated with direct current will read correctly with alternating current if the lag of the current in the ampere coil equals the lag of the current in the volt coil. Another erroneous theorem is that the power factor of a synchronous motor is unity when its excitation is adjusted so that the current it is taking is a minimum. Numerous examples could be given from the theory of polyphase currents where it is customary to represent the effective values of large numbers of periodic functions by lines drawn in one plane. This may sometimes be admissible as a first approximation, but it is advisable always to bear in mind the limitations of graphical theory, as this explains the various apparently anomalous results that are sometimes obtained in practice.

The above conclusions are in agreement with those obtained by Dr. W. E. Sumpner in his paper on "The Vector Properties of Alternating Currents and other Periodic Quantities"[1] in which he gives a different treatment of the problem.

[1] *Proceedings of the Royal Society*, vol. 61, p. 465.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m..

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, Ltd., 125, Strand, W.C. Price Two Shillings and Sixpence each.

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Publishers' Cases for binding Vol. 30 of the Journal can now be had from the Secretary or from Messrs. Spon, price 1s. 6d. each.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

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The Three Hundred and Sixty-eighth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 12th, 1901—Mr. W. E. Langdon, President, in the Chair.

The minutes of the Ordinary General Meeting held on November 28th, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members :—

Charles Dalziel Copland.

From the class of Associates to that of Associate Members :—

William Eversley Hardy.

From the class of Members of the late Northern Society of Electrical Engineers to the class of Associate Members :—

J. Sambidge.

Messrs. V. Huskisson and J. A. B. Horsley were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. J. Brown and E. de M. Malan, Associates ; to the *Building Fund* from Mr. J. F. C. Snell, Member ; and to the *Benevolent Fund* from Mr. J. G. Wilson, Associate Member, to whom the thanks of the meeting were duly accorded.

Further remarks made at this point by Professor E. Wilson on the subject of his paper on Aluminium Alloys, as also a vote of thanks to Professor Wilson, have already been reported (v. s., p. 333).

SOME PRINCIPLES UNDERLYING THE PROFITABLE SALE OF ELECTRICITY.

By ARTHUR WRIGHT, Associate Member.

As most power-station managers have now emerged from the trying stage of not having a sufficiency of plant to cope with the amount of business offered them, and have realised that mere largeness of revenue, of lamp connections, or of maximum annual load, do not necessarily imply large profits or commercial success, they are now devoting more time to ascertain what steps should be taken to encourage the continuous accession of profitable business, with the result that a great deal of study and ingenuity is being applied to the subject of this paper. With the object of eliciting the latest views on the subject, and enabling us to agree, as soon as may be, upon the final form to which all sound forms of electricity tariffs should approximate, the writer proposes to discuss some of the fundamental principles which underlie the whole subject of profitable electricity supply, and to outline a form of rational tariff which will be applicable to the great majority of electricity consumers.

The correct designing of Power-stations is closely connected with the subject of the Paper.

At first sight the subject seems allied rather to mere trading considerations than to the scientific investigation of electrical engineering matters, but it is easy to show that, unless some of the principles involved are thoroughly understood, the design and equipment of an electrical power-station might possibly be carried out on altogether wrong lines from an economic point of view. It is also probable that the financial loss incurred by a supply authority disregarding the Hopkinson doctrines of electrical costs, would completely annul all the benefits that should accrue from the use of the most efficient modern machinery and systems of distribution, the selection and management of which have hitherto absorbed nearly all the attention of electrical engineers.

This superiority of load-factor in improvement in reducing costs is demonstrated by the actual results at the Brighton Power-Station whose load-factor has been increased from 11 to 17¾ during the last eight years. Had the present load-factor existed eight years ago, the then total inclusive cost of supplying a unit of electricity would have been reduced by a larger amount than if the whole of the actual expenditure on coal, stores, repairs, and wages at the works had been saved.

Again, the conditions determining the cost of supplying electricity are such as to justify the anticipation of supplying nearly all the interior domestic artificial lighting in a town, provided that a tariff based on proportionality to true costs is adopted, so that instead of erecting small power-stations with the idea of only supplying the few best streets, the design, were these principles recognised, would proceed on the assumption of having to cater for even a larger custom than that of the local gas supply.

It is also scientifically interesting to determine the laws which connect the reduction of costs with the improvement of load and diversity factors and the increase of output, as well as the relative importance of effecting a reduction of the cost by either plant economy or the selection of consumers.

Finally, it is obvious that the lower the price at which electricity can be profitably sold, the greater must be the amount of work in store for us in the future.

Prevalence of hazy ideas on the subject proves that the time is ripe for its thorough discussion.

That the time is opportune for a discussion on electricity costs and charges will be evident when we realise the great confusion of ideas on the subject that at present exists as proved by the following dozen, out of many other, anomalies. In many towns the supply authorities:

(1) Instead of attempting to standardize the tariff system, have as many as seven or eight bases for making out their consumers' accounts, and do not realise the muddle this will inevitably lead to when the consumers number thousands.

(2) After adopting a more or less correct form of sliding scale of charges, deliberately destroy the benefits accruing from such a course by offering

the early closing consumers, or low load-factor consumers, *the option of a cheaper uniform rate* to lessen their accounts.

(3) While willing to supply many consumers at much less than what must ultimately be the true cost price, refuse to sell to others at a price which can easily be shown would produce a profit of 50 to 100 per cent. on the cost. Moreover, they frequently show a most pronounced reluctance to do anything which will discourage the consumption by hopelessly unprofitable consumers.

(4) Are willing to lower the initial price chargeable per unit in the sliding scale, under the erroneous belief that they are thereby benefiting the average consumer, whereas it can be shown that this is the most unlikely way of doing so.

(5) While eager to run their mains in the rich residential districts, hesitate to supply the shopping thoroughfares of the poorer classes, which are generally a more profitable field.

(6) Give discounts based purely on the quantity of electricity consumed, irrespective of load-factor.

(7) Actually discourage the installation of any but constantly used lamps, by giving discounts on the basis of the load-factor of the connected lamps instead of on the actual demand.

(8) Discourage the use of lamps, and thereby the employment of their own capital, during the time most people require light by quoting a high evening rate, and a low day rate.

(9) Agree to an abnormally low initial price per unit being fixed for a power distribution scheme, independent of the power-factor of the supply, or of the cost of distributing the energy.

(10) Adopt a fixed price per unit for public lighting, irrespective of the number of hours per annum during which such a supply is required.

(11) Hope that by making the price uniform and low enough the supply will become so rapidly universal that all necessity for a sliding scale of charges will

disappear, forgetting that the mere size of a business will never alter the fact that the standing-by cost of supplying a 6 per cent. load-factor consumer during the usual lighting hours will always be five times that of a 30 per cent. load-factor consumer.

(12) Believe that in any case nothing should be done to displease the large early closing consumers, who they assume will always be the mainstay of the business, because their custom was so early forthcoming.

This curious state of affairs cannot be due to apathy, to over-prosperity, or to sound reasons of expediency on the part of the supply authorities, as it is only fair to suppose that they are possessed of too much common sense to allow such causes to interfere with the natural desire to trade on ordinary sound commercial lines, so there seems no alternative but to assume that the reason is to be found in either their scepticism as to the soundness of the Hopkinson doctrines, in their incomplete grasp of them, or in their fear of displeasing their early-closing constituents.

Although there is a danger of a lengthy investigation of the subject creating an exaggerated idea of its complexity, the writer proposes to recapitulate a part of what has already been written, in order that the matter shall be now presented in as complete a form as possible.

Determining the true cost of supplying Electricity is the necessary antecedent to the framing of correct charges.

It is obvious that before methods of charging for electrical energy can be properly examined, some approximate idea of the cost of generating and distributing it under varying conditions must be obtained, and no excuse is needed for going rather deeply into this part of the subject.

Hopkinson's and Kennedy's suggestions on the subject.

As is well known, Dr. Hopkinson first enunciated the correct method of determining the cost of supplying electricity in bulk from a power-station under varying conditions, and Professor Kennedy soon afterwards suggested a method by which the cost of supplying the great majority of electricity consumers individually could be approximately arrived at.

Electricity Costs are as dependent on the Diversity Factors and largeness of the total demand as they are on the Load Factor.

Following generally the lines laid down by these two authorities, the writer proposes to examine the problem as it exists to-day, modified by the realisation of the important effect in reducing costs of what is now termed the *diversity factor* of different classes of consumers, and of the magnitude of business.

As a comparatively simple method can be used for approximately determining the cost of supplying nearly 90 per cent. of the consumers of most electric supply undertakings, the writer trusts that his attempts further to develop our views so as to cover most of the remaining 10 per cent. will not intensify the general impression that as the whole subject is such an extremely difficult one, the only practical course is to consider the tariff on the basis of average rather than on individual costs.

The cost of supplying electrical energy from a power-station can generally be separated into two very clearly defined groups, viz:—

Division of Costs into those of Preparation and Production.

A. The cost of *getting ready* to supply and distribute energy.

B. The actual cost of *continuing to do so.* These two groups the writer will call, for convenience, *Preparation* and *Production* Costs respectively.

The *Preparation* Costs may be divided into three sub-divisions:

The three principal sub-divisions of the Preparation Costs.

(1) The annual cost of the initial capital required to start the undertaking, or the *Preliminary* or *Formation Expenses.* This has generally no very definite relation to the amount of business expected to be done. As the business grows, the annual charge to individual consumers to cover this item of expenditure most obviously rapidly diminish.

(2) The annual cost of having to provide and maintain the plant and mains in a condition ready to supply and distribute electricity. These *Standing-by Costs* vary roughly with the annual maximum load to be provided for.

(3) The cost of maintaining the necessary service lines, meters, and attending to consumers' accounts, and complaints, and of collecting the revenue. These *Service Costs* are roughly proportional to the number of consumers.

The *Production Costs* or the costs of continuing to produce and deliver electricity to the consumer, are those which actually vary with the amount of electricity distributed from a given power-station and set of mains. The production cost per unit sold may be defined as the increment of expenditure incurred by making a given set of plant and mains supply an extra unit of electricity. It can only consist of the following items:—

Definition of the Production Cost per unit.

(1) The inclusive cost of fuel necessary to produce and deliver this extra unit of electricity to the consumer's premises.

(2) The cost of the fuel necessary to keep the steam dynamos running longer per day.

(3) The cost of the extra water and oil used, owing to the longer run of the plant and the greater amount of energy supplied.

Items constituting the *Production* Costs.

(4) Possibly some extra wages cost due to stokers and engine attendants having to work slightly longer per day.

(5) The cost of that extra wear and tear of part of the plant, which is solely due to the continued running.

As the writer wishes to lay particular stress on the relative smallness of the production costs to those of preparation in most electric supply businesses, it is perhaps wise to discuss one or two of the many methods for determining their approximate values for any completed power-station which, the writer will assume, has reached the steady extension stage when additional plant and mains have to be put down year by year to meet the increasing business.

The value of the first four items and their total cost per unit delivered to the consumer can be roughly determined by noting the respective amounts spent on each item during two periods of equal length, such as a month or a quarter

Methods of determining the Production and Preparation Costs.

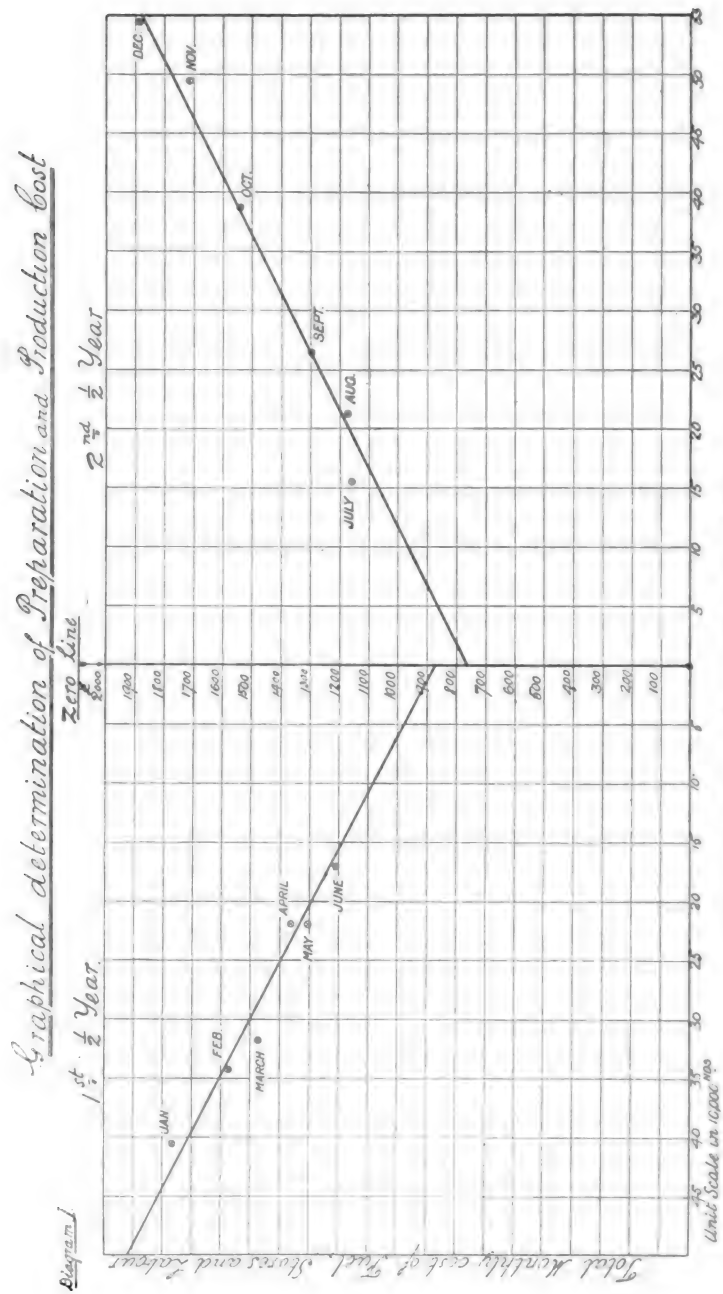


DIAGRAM I.—Monthly Sales of Electricity in Brighton in 1900.

which, having approximately the same maximum load, differ considerably in their respective sales of electricity. The difference of the costs of these items for the two said periods, divided by the difference of the respective sales, will give the average production costs per unit sold. In most towns in spring or autumn, two days can be found which will afford a similar opportunity : for instance, the comparison of an early closing night's costs and sales with those of a late closing night's costs and sales, or those of a bright with a foggy day's results will do. If the difference in costs and sales are sufficiently large to render possible errors in taking the measurements of coal, water, and stores negligible, and the respective maximum loads require the same number of engines and boilers to be used on the two occasions, a fairly reliable result will be obtainable.

Graphical Analysis of monthly Costs.

Perhaps one of the best graphical and most reliable methods of determining the preparation and production groups of costs, is that shown on diagram No. 1 applied to the Brighton Power-Station results of 1900, where the total monthly costs of coal, stores, and labour in the undertaking during the different months are plotted in relation to the varying sales of electricity in these months, the two halves of the year being, for convenience, plotted on opposite sides of the zero sales line. It will be fairly obvious that a straight line run through these monthly costs and extended to meet the zero sales line will cut this at a height representing approximately the average total monthly preparation costs on these three items of coal, stores, and labour for each of the two half years. The difference between any month's expenditure on these three accounts and this total, divided by the number of units sold in that month, will give the average cost per unit of continuing to produce electricity during each of the half years, with the omission of the cost of repairs due to continued production, which, being of a cumulative nature extending over years, has to be separately estimated.

Determining the Cost of Repairs on Production Account.

As to the most correct method for determining the cost of plant repairs on production account there may be considerable doubt, but as they generally form only a very small proportion of the total plant repairs, and merely include the cost of renewing those parts of the plant which

are worn out through *continuing to supply* as distinguished from *continuing to be ready to supply* and consist of such items as extra boiler cleaning, re-boring of cylinders, repairs of pumps, brasses, dynamo brushes and commutators, the writer thinks he is on the safe side when he suggests this item should be taken to be equal to half the total cost of repairs to plant during the last three or four years, divided by the number of units sold during that period.

Relative smallness of the Production Costs in Electric Lighting business.

If station managers were to determine by some such method the actual production costs, many would be surprised at the smallness of the figure. From the writer's experience, he finds that the only items of cost that are appreciably increased by continuing to produce electricity from a given plant for another hour or so are those for fuel and water, and that in the usual power-station neither the cost of stores, labour, or repairs are measurably affected by thus prolonging the running hours of the plant. This is probably due to the cost of these items depending chiefly on the number of engines, boilers, and steam pipes that have to be put in commission to meet the day's maximum load, and not on the number of units the plant has produced. It will be remembered that Dr. Hopkinson's original estimate of the total production costs in a power-station in the Midlands, with coal at 10s. per ton having presumably a calorific value of about 11,000 B.T.U., was a third of a penny.

Having arrived at the approximate value of the total production cost per unit delivered to the consumer, taken over a complete year, the analysis of the debit side of the revenue account of an electric supply undertaking can now be completed.

If the production cost multiplied by the total number of units sold be deducted from the whole of the charges on the debit side of the revenue account, the total preparation charges will remain.

Analysis of the *Preparation Costs.*

From the total preparation costs must now be deducted the service costs which can be separated without much difficulty, leaving the total standing-by cost of keeping the complete system in a state of readiness to supply electricity whenever it is required. If this be divided by the mean of

the last two years' maximum loads lasting half an hour on the distributing mains, the annual standing-by costs per kilowatt demanded (off the mains) will be obtained.

Mean of two years' maximum loads must be the basis of *Standing-by* Costs.

That it is proper to take the mean of the last two years' maximum loads in determining the standing-by costs will be seen when it is remembered that in an expanding business such as that of electrical supply, the plant and mains actually laid down at the end of any year have not probably been available for supply purposes during the whole of that year.

Maximum loads must be calculated on the basis of the *Pressure of Supply* and not of the Power Station Pressure.

As the revenue is derived from electricity taken from the distributing mains, it is the maximum load taken from these and not from the power-station which is the true factor in determining the annual cost per kilowatt supplied to the body of consumers as a whole. In the matter of loss in distribution which is here involved, it is interesting to note that the fuel consumed in magnetising transformers is in practice purely a standing-by loss, and that the losses due to copper resistance of transformers and of feeders and mains form a production cost which has to be allowed for in their calculation. The graphical method above described, however, automatically differentiates sufficiently for practical purposes between all such kinds of preparation and production costs.

The *Cost of Money* must be taken into consideration in determining the Preparation Costs.

In the item of preparation, the bare cost of money must be included, just as much as the cost of superintendence, repairs of buildings, of mains, etc. The cost of money may be taken to be that minimum rate of interest which business men insist upon getting for its use, added to the amount which has to be put aside annually for the redemption of the capital or ultimate renewal of the plant and mains. A capitalist would probably be justified in saying that he would be losing money if he did not at least receive annually 3 per cent. on his investment for interest, and 2½ per cent. for redemption or antiquation of plant from the time he put his money into the undertaking, and in all probability, until electrical undertakings are looked upon with the same confidence and treated by Parliament on the same equitable lines as railways, gas or waterworks undertakings, the average capitalist will require an additional 1½ per cent. for money loaned to companies to provide for the many disabilities with which it has been seen fit to

Definition of the *Cost of Money*.

embarrass the infancy of our industry. A capitalist, in the writer's opinion, would not be justified in stipulating that beyond paying for all repairs out of revenue and the creation of an adequate redemption or antiquation fund, a further provision for depreciation and reserve fund should be debited to the revenue account, as these extra provisions ought to be provided out of the profits when the undertaking has emerged from the struggle incidental to its early years.

Recapitulating, we can now place all the items on the debit side of the revenue account into their proper divisions, viz.:

(1) The total cost of *producing* the units of electricity consisting of fuel, stores, and running repairs of plant.

(2) The total inclusive cost of *preparing* for the supply of electricity, consisting of standing-by fuel, stores, labour, salaries, standing-by repairs of plant, and all other repairs such as those to mains, buildings, etc., management, office expenses, insurance, taxes, etc. The cost of money, consisting of 3 per cent. or 4½ per cent. interest on the whole of the capital, less house service capital, and say 2½ per cent. for redemption of capital or antiquation of plant.

(3) The service costs, consisting of interest on the cost of laying on the house services, the maintenance and cost of reading meters, wages of collectors and consumers' clerks, and repairs of meters and other house-service apparatus.

The loss made in the supply to Small Load-factor Consumers has to be debited to the Revenue Account.

There is one other item of charge which has to be met by the revenue, viz., the loss unhappily incurred in this country in being compelled for various reasons to supply some consumers at less than the actual cost of supplying them. This loss, which in many stations is a very heavy one, must be debited against the revenue account.

Having determined the Costs of Supply from the Mains as a whole, further considerations have to be studied.

Although we can thus obtain a fairly accurate analysis of the various items making up the cost of supplying electricity as a whole from the mains, yet before a true profit and loss account can be prepared, we must determine the cost of supplying the individual consumers, and to do this, many further considerations have to be taken into account.

In the first place, how should the standing-by charges be divided among the consumers having widely varying requirements as to the amount of plant and mains required for their individual service?

The correct apportioning of the Standing-by Charges to the various Consumers

The writer thinks most power-station engineers will now agree that it is fair to debit each consumer with the same proportion of the total standing-by charges, as the amount of plant required for his supply during the evenings of the winter months when the station experiences its annual maximum load, bears to that which would be required to supply the consumers should they all make their maximum demands simultaneously.

As to the most practical method of determining the amount of plant, etc., so required by each consumer, there are many opinions.

Theoretically the best way of determining this data is no doubt some means by which every consumer's daily load curve can be taken and studied, but as this is commercially impossible, the writer is convinced that the next best way is to follow Professor Kennedy's suggestion of supplying each consumer with a maximum demand indicator and to make its rate of recording sufficiently sluggish to prevent the registration of any call for current for only a few minutes' duration. In a purely lighting business, the majority of the consumers will make their maximum call for plant during the two or three hours in the winter days during which the whole of the plant is most heavily loaded, so that by taking the mean of the six winter months' maximum records so measured, a fairly accurate estimate of the proportion of the total plant required by each consumer can be obtained.

Another consideration is, how should proper allowance be given for the well-recognised fact that all consumers do not make their maximum demand for current during the same hours of the evening? A fair allowance for this general diversity in the use of the plant and feeders is best made by dividing the annual standing-by costs per kilowatt demanded off the mains by the ratio of the total of the consumers' individual demands in kilowatts during the month of maximum load, to the maximum load taken off the distributing mains in that month, and debiting each kilowatt demanded by the consumer at this new rate. The above ratio, which has obviously a most important effect in re-

Allowance for the effect of the General Diversity Factor.

ducing the preparation costs per kilowatt demanded by the consumers, may in a general lighting business be as high as 1½, and in a motive power supply business the particular diversity factor among the motors can be much higher. For the purpose of clearness we will take an example in figures. Supposing the sum of all the consumers' December demands has been 1,500 kilowatts and the maximum coincidental demand off the mains has been 1,000 kilowatts, then the diversity factor is 1½, and in apportioning the total of the standing-by costs among the consumers it must be divided by the 1,500 kilowatts to obtain the true standing-by cost per kilowatt. The case of a power-station supplying both the business and residential districts of a town will illustrate the importance of the general diversity factor. As two such districts would probably not make their maximum demands simultaneously, the total amount of plant required would be considerably less than that necessary for the sum of their demands.

Allowance to purely day consumers.

In the third place, how much, if any, should those consumers, who, by reason of their never making a demand for current at the time the station's maximum load is on, and who therefore do not necessitate the supply authority putting down extra plant and feeders for their supply be debited for standing-by charges? This is surely a case of determining the cost of a by-product, and the writer thinks it ought not to be treated as costing anything except on account of production and special service costs, and is fairly met by offering such consumers (who usually only form a very small proportion of the total number) the option of renting a time switch which will put the demand indicator only in circuit during the hours the station plant is heavily loaded with the lighting business. It may be argued that it is hardly fair to use other consumers' plant without giving them some allowance, as a case might happen when the day load might exceed the winter lighting peak, as has already resulted in Montreal from the energetic efforts of Mr. Brown and his staff to get a big day load for his water power-station, but any one visiting Montreal will be convinced that the above result, though startling, is neither the normal nor final state of the electrical supply business in that city, and is due to the temporary neglect of the profitable field of private

lighting, which part of the business in Montreal is apparently negligible at present. So much profitable business can be done by the night supply of electricity for artificial lighting in the majority of cities, as to always ensure very much larger plant and copper being required for this load than for one of power to be only used in the daytime; hence the writer feels that the night users of the investment ought to be debited with all the standing-by costs, as it is their load which renders the expenditure necessary.

The Plant required for the Supply of Artificial Lighting will be greater than that required for Power Supply.

Again, how can due allowance be made to consumers, the intermittent or momentary character of whose use of electricity requires special consideration on the ground of such a class having necessarily a very much higher diversity factor among themselves than that of consumers whose demand for current is fairly constant during the evening from dusk until their closing time? This consideration applies as much to the users of electricity for motive power and heating purposes as it does to the lighting of the occasionally used rooms of private residences, hotels, etc. The standing-by costs per kilowatt of supplying this class of user is as much less than that of the equal load factor regular consumer as the class diversity factor of the former is greater than that of the latter class, and a very fair idea of the proper amount of plant required to supply them in the aggregate can be obtained by measuring their demands by indicators designed to have a sluggishness of registration such that any load or increase of load has to be maintained for at least an hour to be fully registered and that if maintained for any less period the registration will be less. The use of sluggish demand indicators for all classes of consumers will automatically allow to the intermittent light and power users the discount they are entitled to on account of the probable large diversity factor of such classes, and at the same time will register the true demand of all longer maintained loads. It is probably safe to assume that the *class diversity factor* of any large body of consumers will be roughly proportional to the shortness of the time during which they maintain their maximum demands, and it is an interesting problem in the theory of probabilities to determine the proper amount of discount to give on account of shortness of duration of demand.

Allowance must be made to intermittent users on account of their Class Diversity Factor.

Automatic means for allowing for the varying Class Diversity Factors.

Possible objection to the use of very sluggish Demand Indicators.

It may at first sight appear that this method of employing sluggish demand indicators for the purpose of automatically giving a lower rate to intermittent consumers will also benefit the most undesirable class of consumer, such as the occupants of early closing offices, who might only require a supply for one or two months in the year and then possibly only for, say, half an hour at a time, and whose diversity factor cannot certainly be greater than unity. On further consideration, however, it will be seen that the standing-by cost of the supply of electricity to the very small minority of consumers *who never use their maximum demand for more than half an hour at a time* can be made so small by the use of a storage battery charged during the day-time, as to mitigate the rigid application of the usual Hopkinson Law of Costs to this class; in fact, a storage battery reduces the conditions of supply to such consumers to conditions more or less similar to those governing ordinary gas supply, in which the effect of the load-factor on costs is small, and it is quite probable that the inclusive cost per unit to such lighting consumers can be considerably reduced by this means. There are, in fact, a limited number of consumers the nature of whose demand is within the economic capabilities of a storage battery, and we may consider them to the above extent.

Before going into the question of deciding the best form of tariff to adopt, the following notes on comparison of financial results may be useful:—

Suggestions for the comparison of Power Station Results.

(1) It will be evident that only comparisons of the standing-by costs based on *yearly results* are useful, and should be made on the basis of their relation to the mean maximum load in kilowatts we may expect to have to meet in the year in question.

(2) As most of the production costs can be determined after two or three months' or quarters' readings are available, monthly comparisons of them are then possible on the basis of units sold, and calculations can be based upon a constant price and an average quality of coal.

(3) Comparison of service costs must be made on the basis of the number of consumers connected, and can be compared monthly, quarterly, or annually, as desired.

(4) The cost of plant repairs, being of a cumulative nature, can only be compared after three or four years' results are available.

(5) Capital costs, being roughly in proportion to the maximum load provided for, the length of streets supplied with distributing mains, and the number of consumers connected, cannot be properly calculated solely on the basis either of units sold or on the maximum load in kilowatts with which they have no simple relation.

(6) Undertakings with similar load-factors and outputs cannot be properly compared unless the general diversity factors are assumed to be the same. As an example, no proper comparison can be made between the returns of an electrical undertaking supplying the business portion of a city, where the diversity factor may be as low as unity, with another undertaking supplying the residential portions where the diversity factor may be higher than 1·5, notwithstanding the possible equality of the load-factors at the power-stations.

(7) Comparisons cannot be fairly made between electricity supply undertakings owned respectively by municipalities and companies. In the former case, no proper charge is generally made for Town Hall expenses, legal assistance and the Borough Surveyor's services, or for those of the members of the Electricity Committee, who act in the same capacity as company directors, and although municipal electrical undertakings have frequently to put up with troublesome labour clauses in their specifications, have to alter their charges to please prominent constituents, and to suffer from the frequent changes of management generally inseparable from municipal ownership, they are not burdened to nearly the same extent as commercial companies in the way of street works costs, raising of capital, or in the delays consequent on service of statutory notices.

The writer wishes to lay particular stress on the futility of comparing anything but annual results in the matter of

DIAGRAM II.

STEPNEY BOROUGH COUNCIL ELECTRICITY WORKS.

Approximate Revenue Account for Period ending September 30, 1901.

	Year ending Sept., 1900. £ s. d.	Per Unit.	Year ending Sept., 1901. £ s. d.	Per Unit.	Month of Sept., 1900. £ s. d.	Month of Sept., 1901. £ s. d.
Fuel	1,537 1 8	1·01	1,801 16 9	·59	170 1 3	127 0 8
Stores	274 0 5	·18	148 4 6	·04	15 7 2	12 6 6
Repairs, Plant, & Buildings	53 4 11	·03	97 14 7	·03	7 8 7	4 19 8
" Mains	20 7 4	·01	42 8 6	·014	3 3 7	1 16 10
House Service maintenance	27 1 2	·02	91 18 6	·03	2 16 3	37 7 0
Salaries and Wages ...	1,248 18 5	·82	1,718 5 0	·57	125 2 9	128 8 10
Rates and Taxes	175 15 0	·12	189 7 7	·06	7 8 4	12 0 0
Miscellaneous Expenses ...	512 13 5	·34	346 8 4	·11	39 18 9	17 9 5
Interest	2,208 5 3	1·45	2,788 15 7	·92	177 2 10	250 0 0
Sinking Fund	169 6 9	·11	67 5 8	·02	9 11 0	9 12 6
Net Profit						158 2 0
	£6,226 14 4	4·09	£7,292 5 0	2·42	£558 0 6	£758 4 2

	Year ending Sept., 1900. £ s. d.	Per Unit.	Year ending Sept., 1901. £ s. d.	Per Unit.	Month of Sept., 1900. £ s. d.	Month of Sept., 1901. £ s. d.
General Sales ...	2,684 17 9	2·74	5,198 1 1	2·53	369 3 6	583 2 11
Street Lamps ...	1,034 14 10	1·84	1,542 8 10	1·57	99 16 4	153 12 7
Meter Rents ...	78 15 5	2·44	142 15 1	2·23	9 8 10	14 19 1
Sundry Receipts ...	43 2 7		63 12 1		4 9 0	6 9 7
Net Loss	2,385 3 9		345 7 11		75 2 10	
	£6,226 14 4		£7,292 5 0		558 0 6	758 4 2

Units sold year ending—		Max. Load provided for.	Total cost per K.W. minus Coal.
Dec., 1900 ...	366,639 ...	350 K.W. ...	£13·4
Sept., 1901 ...	722,282 ...	500 K.W. ...	£10·95

Units sold—		Load Factor.	Years.
Sept., 1900 ...	37,775 ...	12 per cent. ...	1900
Sept., 1901 ...	71,756 ...	16·45 per cent. ...	1901

preparation costs, revenue returns, and load curves, and invites attention to the form of monthly return cards shown in Diagram II. he has adopted in the supply undertakings he is connected with, also to the method of plotting the annual load curve of a power station such as that shown in the diagram for the Brighton results in 1895 and 1900, and for the past year at the Stepney Electricity Works in Diagram III. This form of plotting the station working is, in his opinion, the most useful form station managers can employ. It is obtained by mechanically adding together the number of hours during which any given load from the distributing mains has been supplied during the year.

Plotting the *Annual Load Curve* of a Power Station.

From such a curve, with suitable scales, can be determined various useful data, among which are :—

(1) The load-factor at which any proportion of the total plant has been used. This is equal to the abscissa at the given load.

(2) The relative importance of the production costs to the preparation costs for any given load. This is shown by the ratio of the abscissa to a given ordinate.

(3) The total cost of producing electricity at any given load. This is proportional to the sum of the abscissa and the ordinate.

(4) The number of units sold annually at a given load. This is equal to the abscissa multiplied by the ordinate.

(5) The maximum losses economically allowable in the feeders.

(6) Only from such a curve can be determined what proportion of the plant should be supplied with full equipment of coal-saving apparatus, such as condensers, economisers, etc.

Unless some idea of the form of this annual load curve is known, it is quite possible for an electricity undertaking to be laid out on wrong lines. It must be obvious that all the peak of a curve should be supplied from plant put down, having in view rather the lowness of capital costs, of standing-by coal, and the small amount of labour required, consistent with thorough reliability of service, than economy

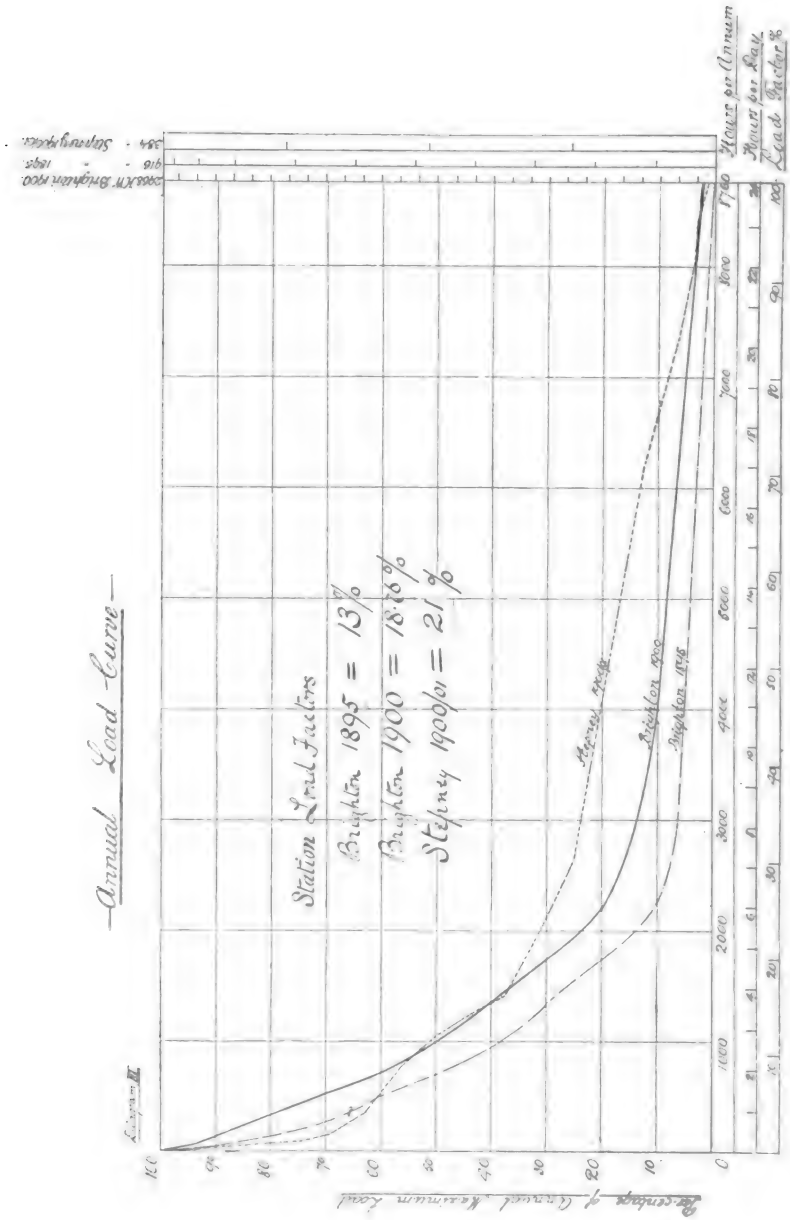

Annual Load Curve
Station Load Factors
Brighton 1895 = 13%
Brighton 1900 = 18·76%
Stepney 1900/01 = 21%
Hours per Annum
Hours per Day
Load Factor %
Percentage of Annual Maximum Load

DIAGRAM III.

in coal on production account. As the Brighton curve represents the general lighting business which may be expected in an average English town, the exceedingly poor load-factor of more than half the capital in such businesses becomes apparent from its study.

ANALYSIS OF CHARGES TO REVENUE ACCOUNT OF THE BRIGHTON ELECTRICITY UNDERTAKING IN 1900.

(*Automatically determined by the Graphical Method.*)

ACCOUNT.	1. *Production Costs*, or those items incurred by continuing to supply, after the plant, etc., have been provided and got in readiness, and which vary with the number of hours the lamps are used.	2. *Preparation Costs*, or those items which do not vary with the length of time the lamps are used.	3. *Service Costs*, which are in proportion to the number of consumers, and independent of their use of the lamps.	TOTAL.
	£	£	£	£
Coal	7,920	3,231	...	11,151
Oil, water, and engine stores	310	1,020	...	1,330
Wages at works	...	5,355	...	5,355
Repairs to buildings ...	...	885	...	885
Repairs to machinery and plant	1,085	588	...	1,673
Repairs to mains	...	1,376	...	1,376
Repairs to meters ...	...	...	1,013	1,013
Fuse replacements ...	...	...	101	101
Salaries of permanent staff	...	1,375	1,202	2,577
Current expenses ...	...	464	...	464
Rates and taxes	...	1,237	...	1,237
Insurances	...	145	...	145
Printing and stationery ...	...	317	...	317
Law expenses	...	11	...	11
Interest and Sinking Fund	...	18,312	1,160	19,472
	£9,315, or $\frac{6}{10}$ths of a penny per unit sold.	£34,316, or £9 13s. 4d. per kilowatt demanded by the consumers.	£3,476	£47,107

Large proportion of the total Coal Consumption used for Standing-by in an economically worked Station.

From the accompanying analysis of last year's Brighton results, it will be seen that nearly half as much coal was used in keeping the plant in a position to supply as was used in actually producing the current, although the average cost of coal per unit was only ·72d., a very moderate figure considering that the price paid was over 25s. per ton. From this fact may be inferred how important it is to study carefully the best means for reducing the heavy stand-by coal losses in the case of a lighting supply plant, and the danger in assuming that the whole of the coal bill is due to the actual *production* of electricity.

From the same analysis it will also be seen that the bare cost of supplying any one individual consumer in Brighton with electricity in the particular year under study was £9 13s. 4d. per kilowatt, or 6s. 2d. per 32-watt lamp, demanded by the consumer, and ·6d. per unit consumed, plus the service cost, which ought to have been covered, but was not half covered by the meter rental.

A Profit and Loss Account, embodying the above principles drawn up in a complete form, is shown for the Brighton results in 1900.

A real loss is incurred in selling Electricity at less than the equivalent of the preparation and production costs.

The writer will have entirely failed in his endeavour to put the case clearly unless he has shown that the undertaking does incur a *real loss* by selling electricity, under the assumed conditions of the supply to the majority, at less than the equivalent of the combined two charges of standing-by and production, which, turned into the cost per unit sold, work out for the Brighton Station as shown on the accompanying table and curve IV. of the cost per unit for electricity used under varying load factors. This table and curve has been obtained by dividing the above mentioned £9 13s. 4d. per kilowatt demanded, by the number of hours of use in the year and adding to it the production cost. The curve shows graphically the rapid reduction in total costs due to a lengthened use of the plant, and the sloping line on the same sheet shows how slowly the total cost of supplying a consumer with a given demand increases with the number of hours in the year he uses the same.

The actual cost of supplying a unit at Brighton in 1900 under varying Load Factors.

It is interesting to note that the cost of producing and supplying double the quantity of electricity to that actually sold in 1900 from the same plant would only have increased the charges to the Revenue account by 17½ per cent.

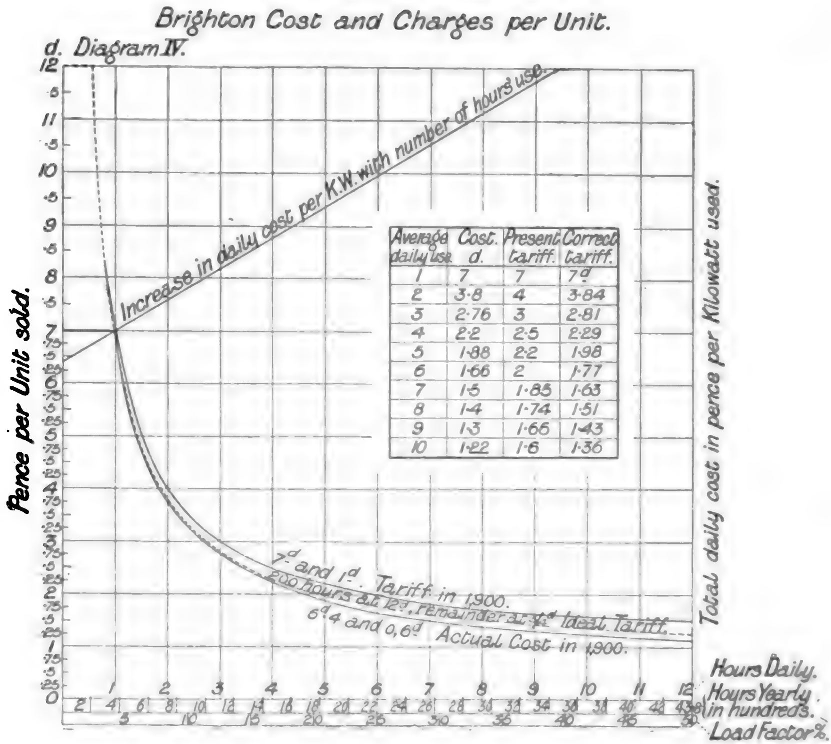
STATEMENT SHOWING THE SOURCES OF PROFIT AND LOSS AT BRIGHTON IN THE YEAR 1900.

To LOSS ON SUPPLY to 524 consumers who did not consume the equivalent of the use of their demanded number of lamps for 365 hours during the year :—				
PREPARATION COSTS :				
375 kilowatts at £9 13s. 4d. ...	£3,616			
PRODUCTION COSTS :				
65,860 units at $\frac{6}{10}$ths of a 1d. ...	160			
		£3,775		
Less REVENUE from above consumers		1,921	£1,855	
To LOSS ON SERVICE ACCOUNT.				
SERVICE COSTS		3,476		
Less METER RENTALS, etc.		1,640		
			1,836	
BAD DEBTS :				
Amount provided		186		
Less Balance brought forward		14	172	
			3,863	
To Balance : NET PROFIT			507	
			£4,370	

BY PROFIT on first hours' supply to 2,331 consumers who consumed more than the equivalent of the use of their demanded number of lamps 365 hours during the year.				
REVENUE from sales 1,159,878 units at 7d. ...		£33,800		
Less PREPARATION COSTS :				
3,175 kilowatts at £9 13s. 4d.	£30,700			
PRODUCTION COSTS :				
1,159,878 units at $\frac{6}{10}$ths of a 1d.	2,900			
		33,600	£200	
BY PROFIT ON SALES after the first hour to above consumers :				
REVENUE from sales, 2,501,985 units at 1d. ...		£10,425		
Less PRODUCTION COSTS :				
2,501,985 units at $\frac{6}{10}$ths of a 1d.		6,255		
			4,170	
			£4,370	

In order to determine how cheaply electricity can be supplied in other towns, the writer has analysed on the foregoing principles the results of one of the most economically run municipal electrical undertakings, viz., that of Nottingham, for the year ending March, 1900, and assuming, for want of proper data, the diversity factor and price of coal shown, he has calculated the load factor curve of costs. The curve V. exhibited shows how the actual tariff favours

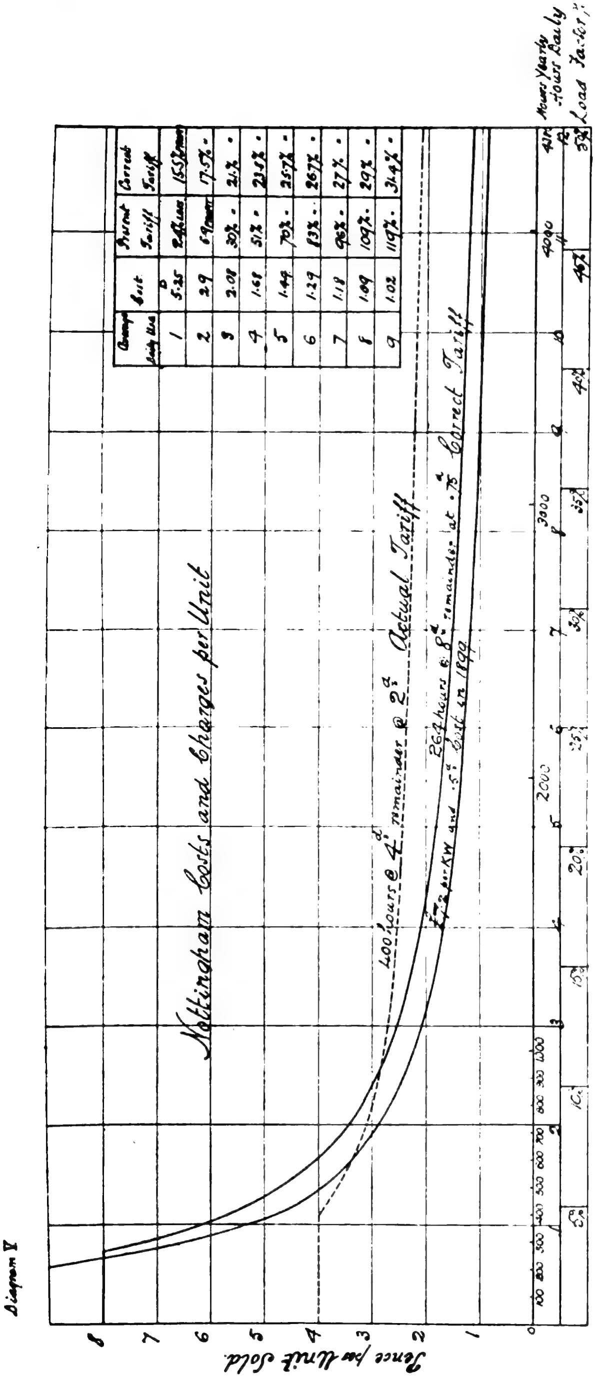
Analysis of the results at Nottingham in 1899.



Average daily use	Cost. d.	Present tariff.	Correct tariff.
1	7	7	7d.
2	3·8	4	3·84
3	2·76	3	2·81
4	2·2	2·5	2·29
5	1·88	2·2	1·98
6	1·66	2	1·77
7	1·5	1·85	1·63
8	1·4	1·74	1·51
9	1·3	1·66	1·43
10	1·22	1·6	1·36

DIAGRAM IV.

the early closing community to the disadvantage of the profitable later closing classes. From the curves can be seen what might have been the correct form of tariff, also the number of hours use of each consumer's demand which must be paid for at eightpence per unit in order to recoup the supply authorities' out-of-pocket expenditure. It will be seen that electricity cannot be supplied without actual loss at less than 5¼d. per unit to the class who only use



Average Daily Use	Cost	Present Tariff	Correct Tariff
1	D 5.25	[illegible]	155% [illegible]
2	2.9	6.9 [illegible]	17.5% "
3	2.08	30% "	21% "
4	1.68	51% "	23.5% "
5	1.49	70% "	25.7% "
6	1.29	83% "	26.7% "
7	1.18	96% "	27% "
8	1.09	109% "	29% "
9	1.02	119% "	31.4% "

Diversity Factor = 1·3 ; Cost of Coal = 15s. per ton.

DIAGRAM V.

their demand 365 hours, or say, have a 4 per cent. load factor, and that under the tariff adopted of 4d. for 400 hours and 2d. afterwards, the three-hour consumer actually was made to pay 12 per cent. more than his fair share of the charges, and the one-hour consumer obtained his electricity at less than 70 per cent. of its cost.

The difficulty of avoiding making a loss on the supply to the very small Load Factor Consumer in England.

The losses made on the supply to the small load factor consumers are owing to our having to contend with the persistent but erroneous impression that the cost of supplying electricity is in some very near proportion to the amount consumed, as is the case with candles, petroleum, and gas, and such are the influences at work that it now seems hopeless, in some districts, entirely to resist the demand for electricity charges being based on the units consumed instead of on the commercially sound principle of a charge compounded of kilowatts demanded and units consumed.

The possibility of one tariff being devised which will fairly deal with all classes of Electricity Consumers.

Having now detailed the method of determining the cost of supplying nearly every class of electricity consumer met with in practice, no matter how varied their load or diversity factors, it remains to be seen whether one tariff can be devised which will fairly meet all varieties of electricity consumers, and at the same time be in a form best calculated to increase the profitable sale of electricity in the shortest possible time. The latter is, or ought to be, the common object of Companies as well as of Municipalities, although their respective ideas as to the amount of profit to be made, and the methods of effecting this object, may differ considerably in each case.

It is now becoming generally recognised that the chief aim of municipality supply managers should be to ensure the general use of electricity among all classes of ratepayers, consistent with making a sufficient margin to cover contingencies, whereas the only aim of a company is the annual return to the shareholders of as large a percentage on their investment as possible, consistent with the proper discharge of their obligations. However divergent these two aims may at first sight appear, on further study it will be found that owing to the special conditions governing the cost of supplying electricity above described, the real aim of both classes

of supply authorities should be to obtain the custom of the middle class small householder and shopkeeper.

The poorer householders in a town are so much more regularly at home and make their purchases so much later in the evening that the lighting of their districts offers a much better load factor for the supply authorities' capital than that of the richer classes, who are frequently away from home, and do most of their shopping before dusk. Again, the number of artificial light users is so much greater per square mile in the poorer districts of a town as far more than to counterbalance the extra cost per lamp of connecting their smaller premises to the distributing main.

The reason of the greater profitability of the Supply to the middle class districts of a town.

It must be noted that whilst there is generally no difficulty in finding customers among the richer classes for the electric light, owing to its greater convenience, the obtaining of the custom of the bulk of the community must always depend largely upon the fixing of a low average price, which may be seriously hindered by the adoption of a wrong tariff. The supply to the many small householders and poorer shop-keepers in any town must therefore be the first consideration in determining upon a system of charge; no steps should be taken which will raise the cost to this class above what is necessary to provide for a fair share of the ultimate net profit and of the reserve fund.

The custom of the wealthier users of Artificial Light is obtained without difficulty whatever tariff be adopted.

A study of the curves of costs will demonstrate that electricity can be profitably supplied to the class of consumers who use their lamps on the average three or four hours per day throughout the year at a sufficiently low price to make it in many cases cheaper than that of gas, as generally used by them. It is fortunate, therefore, for the future of our industry that the great majority of artificial light users belong to such a class, although the majority of present consumers of electricity do not belong to it. This is due to:—

The average middle class user of Artificial Light can be as cheaply supplied with Electricity as with Gas.

(1) The natural effect of the various imperfect systems of tariff until recently in vogue in many towns.

(2) The practice of only running distributing mains in the parts of a town where the wealthier inhabitants reside or do their shopping.

(3) The initial cost of wiring, and the present legal

Reasons why the present Electricity consumers have not the average load factor of the great bulk of Artificial Light users.

inability of municipalities, and the unwillingness of supply companies, to assist in this matter.

The Competition of Gas would not be serious if the Supply Authorities were to undertake to do the interior wiring on the hire-purchase system.

There can be no doubt that if supply authorities were to provide the interior wiring (on the principle of the hire purchase system) and adopt a form of tariff which charged the small load factor consumer with at least the bare cost of supplying him, and which represented a modest scale of profits, even although it should be negative or negligible during the first two or three years, the inclusive charge for supplying the electric light to the average artificial light user could be made low enough to defy the competition of gas.

Curves showing the effect of increased demand on reduction of costs, lowness of average price on increase of business and the inclusive profitable price per unit for the supply of wiring and electricity.

The four curves, Nos. VI., VII. and VIII., IX., derived from the results obtained at Brighton, where distributing mains have been very freely run, will prove the correctness of the above assertion as to the relation of low cost and rapid extension of business among consumers who form the bulk of the middle-class community. The first two curves show how the standing-by, the production and the average costs per unit were reduced as the total demand for the supply increased, and the effect of the persistent encouragement of good-load factor consumers in improving the power station's load factor. The third curve shows the marked effect of a reduction in price on the increase of business, and the other curve shows at what rate per 16 c.p. lamp per annum and per unit electricity can be supplied to even a small five-light installation, to include the use of wiring and all house service charges. From the last curve, it will be seen that small premises, which, on the average, require the use of artificial light for three hours per day, or say until 9 p.m. throughout the year, can be wired and profitably supplied with electricity at a lower price per candle power than can be done with gas as generally used on such premises.

It remains then to consider whether this large class of possible consumers can be most quickly secured by adhering to the plain flat rate of charge, or by adopting a tariff in which the charges to all classes of consumers follow approximately the cost of supplying them individually. That is to say, whether the custom of the middle and poorer classes can be more rapidly obtained by means of a rate dependent entirely on the quantity consumed, as in

the case of gas, or by means of a system of charge which, though less simple, enables the average user to obtain a service at a lessened annual charge, as in the case of the modern telephone charges. In other words, will the majority be more attracted by simplicity of charge, or by low annual cost, since it is easy to show that these deside-

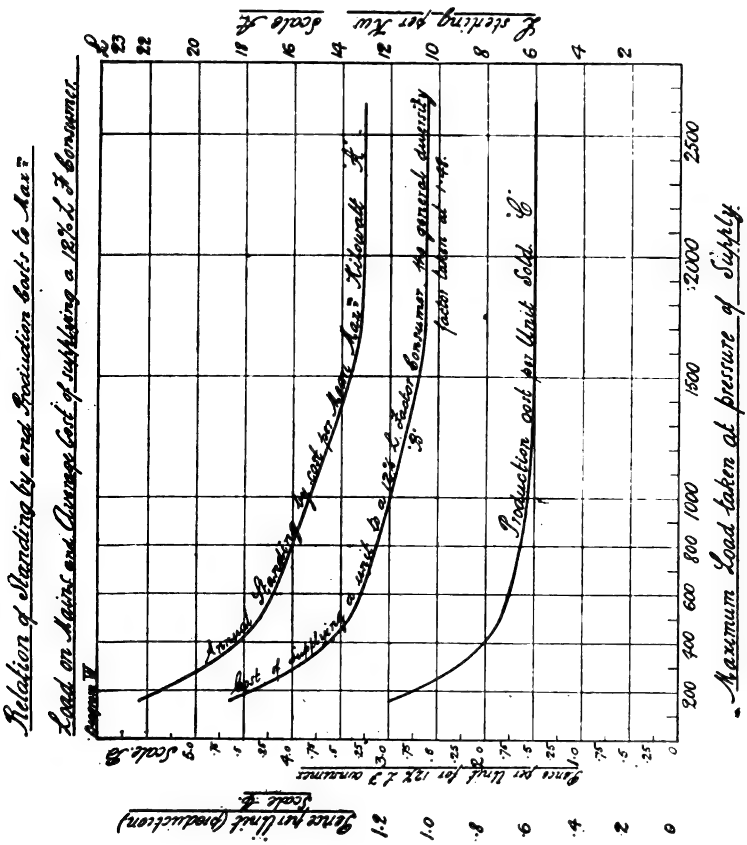


DIAGRAM VI.

rata cannot both be obtained by the same tariff. We must bear in mind that the popularity of the form of tariff does not necessarily imply the popularity of the service given.

A uniform price to all classes involves the long hour consumer paying for the loss made on the short hour consumer, thus making the price to the long hour class higher than it otherwise need be. It follows that a uniform charge per unit means a higher price to those who use the

The more we cater for the custom of the early closing consumer the longer must the Electric Light remain a Luxury.

electric light for three or four hours, than does an equitable differential tariff. This taxing of the good-load factor consumer for the benefit of the bad one must encourage the latter and seriously discourage the former, which obviously implies an unnecessarily poor-load factor for the whole undertaking, which in turn raises the average cost. A uniform charge, therefore, keeps the cost and charges to the majority of possible consumers unnecessarily high, and it keeps the business and load factor of the supply authority unnecessarily low.

Uniformity of charge per unit must imply unnecessarily higher costs and charges than a differential tariff.

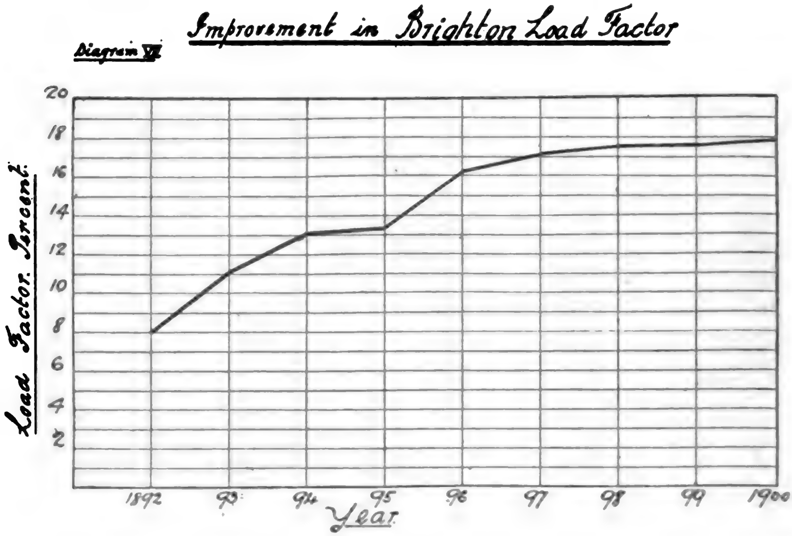


DIAGRAM VII.

System of discounts to all large Consumers acccentuates the disadvantages of the system of uniform rates.

The bad effects of the flat rate system are further accentuated by the custom of working it in conjunction with a system of discounts to large annual consumers, without any reference to their profitability, based on the fallacious assumption that larger consumption necessarily involves greater profit. This indiscriminate discount to large consumers is another mischievous inheritance from the erroneous analogy of the gas business.

Large consumers can very possibly be sources of loss while small ones frequently are the chief sources of profit.

How inexpedient is this discount system may be seen from an example of two consumers, one large and the other small, both paying the same rate per unit, where the former may easily be a source of loss, while the latter is a source of profit. For instance, a consumer using one

thousand lamps 365 hours per year and paying a uniform charge of 4d. per unit, will have an account of nearly £400 to pay, and most supply authorities would make a loss on his account, whilst another consumer using only ten lamps three hours per day, charged for at the same rate, will only have an account of about £12 to pay, and will certainly be a source of profit. This large account discount system, while it encourages the custom of the few theatres, hotels, and restaurants, at the same time encourages the custom of a far greater number of large early-closing businesses and blocks of offices.

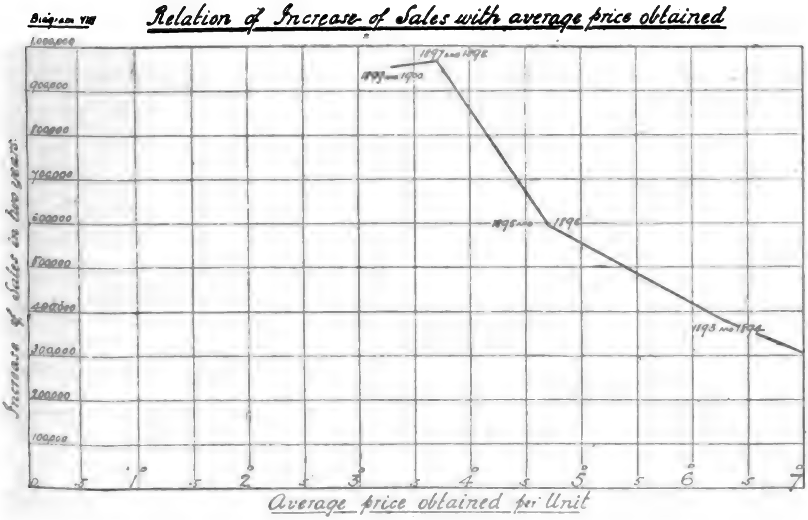


Diagram VIII.

The diagrams on Sheet X. show how the present consumption of electricity at Brighton is divided among the different classes of consumers, the number of units sold to the various classes, the total amount of net loss or profit made on their custom on the existing tariff, and the net return on the capital allocated to the supply of each class. The losses made in the classes using electricity less than one hour per day are due to the insufficiency of the maximum allowable charge, viz., 7d.

The present and probable market for the Electricity Supply Business in Brighton.

Owing to the operation of the three causes previously mentioned, it must not be taken for granted that this division of consumption among the various classes repre-

sents the natural market for electricity supply in Brighton. The dotted line on the first diagram indicates the writer's idea of what may be the probable form of the artificial lighting business curve when the wiring problem is dealt

Inclusive Charge for Wiring and Electricity.

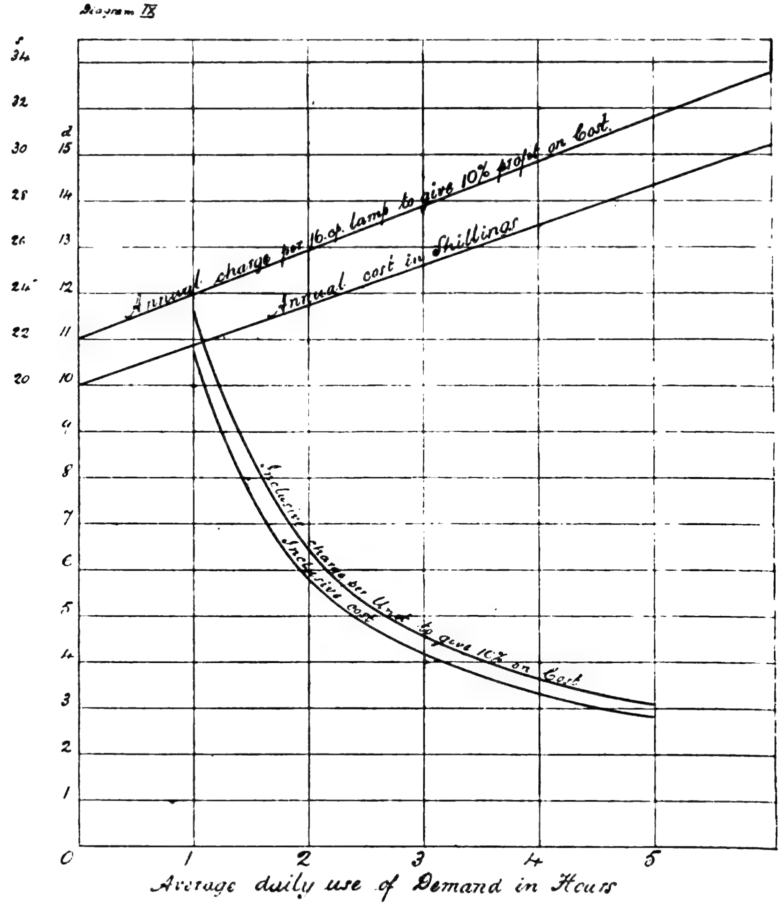


DIAGRAM IX.

with and all the poorer districts of the town are provided with distributing mains.

The results at Brighton prove that neither differential tariffs nor initial high rates have any retarding effect on the growth of the business.

That a differential tariff has no real retarding effect on the general growth of an electrical supply business must be apparent when it is recognised, that not only *the use of electricity per inhabitant*, but also the *annual increase of use per inhabitant* has been in Brighton as great as, if not greater than,

in any other town in Great Britain, and differential tariffs have been in use there ever since April, 1883, when the original really sound form of Hopkinson tariff, viz.,

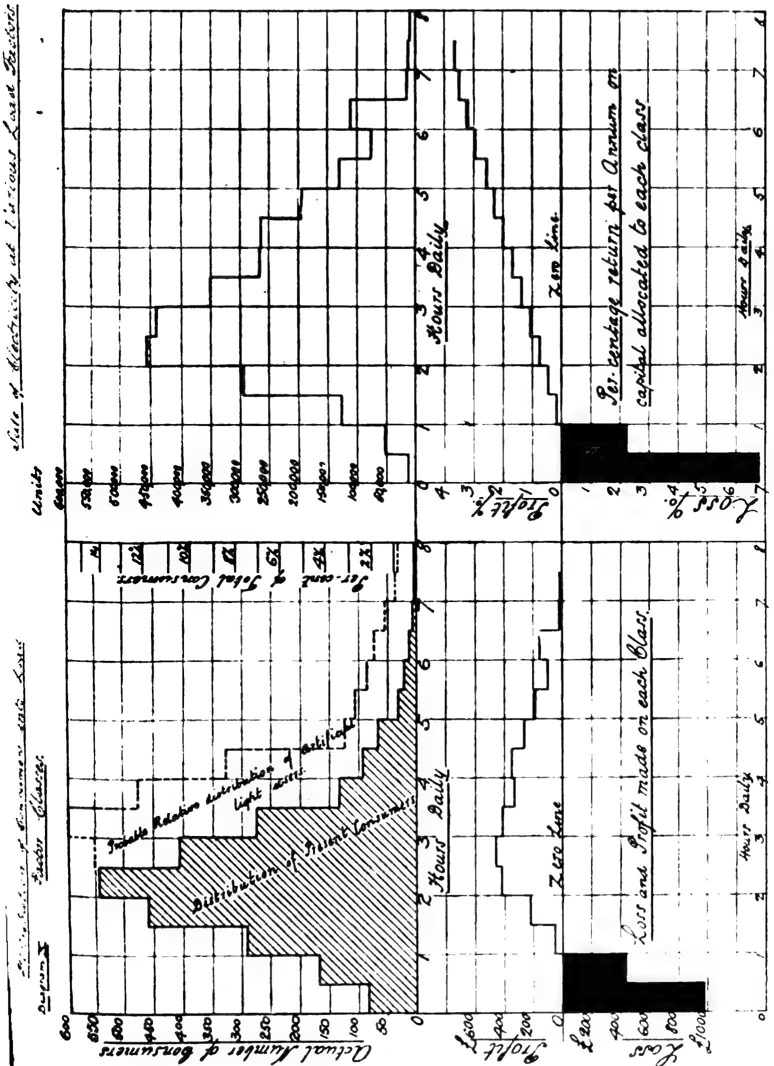


DIAGRAM X.

an annual rent per lamp actually used in conjunction with a charge proportional to the number of hours per annum of such use, was first inaugurated. It is very likely that the differential tariff in use there will make the annual con-

sumption per inhabitant to be more than fifty units in less than five years from now.

The real factor in promoting a rapid and profitable Extension of the business is the lowness of the annual bill to the middle classes.

It will be found that whether municipalities or companies are the supply authorities, equity of tariff, with its consequent necessary concomitant of a lower average price, is much more essential to the rapid general adoption of electric lighting than mere uniformity of charge per unit. It is often urged in favour of the uniform tariff system that in an electricity supply business, as in most others, it is necessary to take the bad with the good, but the writer knows of no business consisting in the supply of *one* commodity which willingly carries out this happy-go-lucky policy when it can easily be avoided by a little thought and trouble.

In the business of Electricity Supply there is no real necessity to take the bad with the good business.

There is another form of tariff which, although not definitely following the Hopkinson Law of Cost, has at times been viewed with favour by power-station managers, and is of great interest.

The Kapp two-rate meter system.

The Kapp two-rate meter tariff is the one referred to, which charges a low rate for electricity consumed during the daytime when the plant is lightly loaded and a high rate during the evening. The inevitable effect of this form of tariff must be to discourage the use of electricity when the majority of men want it, in order to encourage the use of it when the majority of men have no use for it. It seems to have been overlooked that by charging a high rate per unit during most of the hours when artificial light is usually required, the business of every day supply to the average householder is rendered prohibitory. Surely, if a consumer once makes it necessary for the supply authority to instal plant and mains for his service he should be encouraged in every way to use such plant and mains as often and for as long as possible.

This system discourages the use of the Plant, &c., at the very time most people would naturally use it.

The Kapp system charges the profitable 12 per cent. Load Factor consumer three times as much as the 4 per cent. unprofitable one.

The two-rate meter system aims at encouraging the use of electricity when very few can make use of it, but it also actually discourages the use when the majority want it. Moreover, it makes the profitable three-hour consumer pay three times as much for lighting his premises as it does the unprofitable one-hour consumer, instead of the latter having to pay very nearly as much as the former. In the writer's opinion, the two-rate meter system entirely underrates the

value of the artificial lighting business, and is based on an exaggerated idea of the amount of business obtainable in the daytime.

In most controversies, however, there is generally a substratum of truth underlying many of the strongly held opposing views. Thus the old tariff of a fixed price per lamp per annum was nearly as unsound as that of a uniform charge per unit has been shown to be, but the combination of the two constitutes the more correct Hopkinson tariff.

Most of the tariffs that have survived possess some good features which can be embodied in the correct ones.

Again, the system of giving discounts on large consumptions is commercially sound provided that a correct Hopkinson tariff is blended with it. A very large consumer charged on this basis is entitled to a special discount for either or both of the two following reasons. If his account be large because of his demand being large, his large custom may materially reduce, at all events in the early years of the undertaking, when there is an ample margin of buildings and mains, the average preparation costs per kilowatt, or if his consumption be large by reason of his prolonged use of the plant, the percentage of profit made on the *investment* allocated to meet his supply is greater than the average. Discount based on largeness of account should, however, be so regulated as to permit of other consumers, and the shareholders, in the case of a company, benefiting by it. As the relative reducing effect of a large consumer on the standing-by costs becomes less as the total business grows larger, the rate of discount given off such large accounts should gradually diminish as the total undertaking grows in size.

Reasons why some large Consumers may be entitled to an extra discount.

Again, the Kapp system of cheap day supply can be made commercially correct provided it be associated with the encouragement afforded by a Hopkinson tariff to use the plant during lighting hours.

The practice commonly adopted of quoting a lower rate for power purposes than for light has some justification from theory, in that the diversity factor among the particular motors is generally much greater than that among artificial light users, but unless there be a check on the maximum demand made by some form of Hopkinson tariff, there is a danger of the supply authority having periodically to meet a very high load of short duration when works and

factories start up after meal times or at 5 p.m. in the winter months, when the lighting and motor loads overlap. Under a system of a low flat rate for power any early-closing consumer can obtain electricity for artificial lighting through the medium of a motor generator at a much lower price than he could obtain it direct from the mains, which is, of course, an absurd anomaly.

Lastly, the system of charging entirely on the basis of units consumed can be made sufficiently correct for all practical purposes, provided only that a high enough initial charge per unit consumed be made, and this high rate be maintained for a sufficient number of hours per annum to cover the standing-by and production charges. The losses then made on small load-factor consumers will be negligible.

The various apportionment of the total profit required among the various classes.

To complete the basis on which to form our single tariff, it is necessary to consider in what manner the total requisite profit should be distributed over the charges to the various classes of consumers. For instance, will it best further the object municipalities and companies respectively have in view if they seek to make:—

(1) A fixed percentage of profit on the inclusive cost of each unit sold, or
(2) A fixed amount of profit per unit sold, or
(3) A fixed return on the capital involved in supplying any consumer irrespective of the amount of electricity supplied from such capital, or
(4) A profit derived partly from a percentage on the amount of the particular investment and partly from a fixed amount from each unit sold; or
(5) A percentage of profit, whether made per unit sold or on the capital involved, varied so that the largest class of artificial light users may be specially encouraged to take a supply by a lower rate of profit being expected from them than from the smaller classes.

Municipalities should aim at making every consumer pay an equal rate of profit on the inclusive cost of supply.

Municipalities cannot be justified in selling electricity to one class of their ratepayers at a lower percentage of profit than to another class, unless compelled to do so by the terms of their Provisional Orders. There is no doubt, therefore, that in their case the firs method is the correct

one, viz., a fixed percentage profit on the inclusive cost per unit, including sufficient to provide for a reserve fund and contingencies. Thus, if 1 per cent. on the total capital be required for these purposes, and this is equal to, say, 4 per cent. on the total charges to revenue account, then the tariff has to be such that every unit sold has to produce a net profit equal to 4 per cent. of its inclusive cost.

Companies should cater for those classes of artificial light users which are the most numerous.

A company is obliged in the nature of the case to take a different standpoint in regard to the tariff problem. In its case equity of tariff has to be subordinated to the making of adequate commercial profits and very often to expediency, but as there is generally some difficulty in raising the capital in the early stage of the enterprise, it must always be inexpedient to lock up money in supplying consumers whose custom will not ultimately produce a total return of at least 5 per cent. on it; in fact, it might be quite justified in refusing from the first to take on business which it could not be shown would ultimately produce a total 10 per cent. return on the capital allocated to this said business. A company, therefore, should be careful to frame its tariff in such a way as not to spoil its future chances of expanding by quoting too low a price at first to the easily acquired early closing consumers. Moreover a Company would be unwise in framing its tariff in such a manner that the large load-factor consumer was charged at a lower rate than was necessary to obtain his custom, irrespective of equality of profits. Its chief endeavours should be to encourage the custom of that class which is the most numerous and the most profitable to supply at prices which can compete with gas, viz., late shopping and middle-class residential districts.

The injurious effect on both the small consumer and the Supply Authority of the English restrictions in the matter of maximum price and minimum consumption.

In Great Britain, unfortunately, it has hitherto been the practice of Parliament to fix a maximum to the price paid per unit, irrespective of the size of the town supplied. It would have obviously been much better for the small consumers if a limit had simply been put to the general average price of electricity in the town. Again, any consumer in this country can demand to be charged entirely on the basis of units consumed, and, moreover, need not guarantee to take more than 20 units per quarter irrespective of his demand. These three conditions necessarily

raise the cost of electricity to the middle classes, as these, if they use electricity at all, have to make up the losses incurred in supplying the large consumers with low-load factors and the irregular users. It is to be hoped that future Provisional Orders will provide some more effective means than at present exist of protecting the interests alike of the small consumer and of the supply authorities.

The unwisdom of any Supply Authority making the initial price lower than the maximum price fixed in their order.

Dealing with present conditions, however, the maximum price per unit generally allowed in this country is eightpence. From what has already been stated, it will be seen that no supply authority is wise in lowering this price to any consumer until the consumption charged at this rate covers all the standing-by charges incidental to his supply, in addition to the production costs of this part of his consumption and the proper share of the required profits.

To find how much electricity any consumer has to pay for, at this maximum rate, the following calculation is necessary :—

Rules for calculating the basis for an equitable tariff.

If $D =$ the consumer's demand in kilowatts as defined in the preceding pages ;

$K =$ the annual cost of standing-by in pence of each kilowatt so demanded ;

$M =$ the maximum price allowed to be charged per unit ;

$p =$ the production cost per unit ;

$u =$ the total number of units expected to be sold in the year in question ;

$\frac{1}{r} =$ the ratio of the net profit to the total charges against revenue account ;

$L =$ the total loss in pence expected to be made on the supply to the small load-factor consumers ;

$D \times H =$ the amount of electricity that has to be paid for at M pence per unit before the second price P is charged ;

then—

$$D \times H = \frac{DK\,(r+1)}{Mr - p\,(r+1)}$$

$$P \text{ in pence} = p\left(\frac{r+1}{r}\right) + \frac{L}{u - \Sigma D \times H}.$$

As an example, take the Brighton figures of 1900.

Here $M = 7$, $K = 2{,}320$, $p = \cdot 6$ pence, let $\frac{1}{r} = \frac{1}{10}$, $L = 880{,}000$ pence, $u = 3{,}726{,}000$ and $D = 1$ kilowatt.

$$\text{The } D \times H = 403 \text{ units, or}$$
$$H = 403 \text{ hours, and}$$
$$\text{if } \Sigma D = 2{,}950,\ P = \text{one penny,}$$

or after a consumption equivalent to the use of the maximum demand for 403 hours, the price can be reduced from 7d. to one penny to produce the required margin of profit.

The margin of net profit made beyond the 3 per cent. to 4½ per cent. already charged to the revenue account must be such as to allow of an additional discount being given at the end of the year to all large consumers whose accounts exceed a certain figure, and whose annual consumption of electricity has been in excess of the quantity represented by their demand used for H hours.

Meter rentals should be maintained.

The meter rentals should be sufficient to cover service costs, notwithstanding the frequent tendency of gas companies to abolish them.

The tariff can be stated in two equivalent forms

The proposed tariff can be stated in two forms. The first is :—A charge of eightpence per unit, or higher where possible, for that part of the consumption which is equivalent to the use of the consumer's demand for . . . hours a year, or quarter, or month, whichever period is considered most suitable for the district, and . . . pence for any further consumption in the said period. The second form (which is equivalent to the first in the case of all but the smallest load-factor consumers) is stated in terms of a yearly or monthly charge per lamp demanded and a charge of . . . pence per unit for the electricity consumed.

Formula for converting the first form of tariff into the second form.

If L = the yearly rent in shillings of each demanded standard lamp—

M = the highest price allowable, and

P = the price per unit after a consumption equivalent to H hours use of the demand;

W = watts of standard lamp;

$$L = (M - P)\,\frac{WH}{12{,}000};$$

thus if $M = 8d.$, $P =$ one penny, and $H = 365$ hours, and $W = 33$, then a tariff of 8d. for the equivalent of the use of a consumer's demand for one hour per day and 1d. afterwards is the equivalent to an annual rent of seven shillings per lamp demanded and one penny for every 30 hours' use of such standard lamps.

The initial price per unit must never be lowered below the maximum allowed in the Provisional Order.

As the business grows the number of hours during which the highest price chargeable is maintained can be reduced, but the initial price should on no account be altered. This reduction of hours in conjunction with a reduction in the lower price P gives all the elasticity required by the lower costs due to increased output and greater economy of production.

The second way of declaring the tariff, coupled with the explanation that the demanded number of lamps is taken to be the number of standard 8-c.p. lamps, or their equivalent, which have been used simultaneously for about an hour in the six winter months, will enable any intending consumer to estimate fairly correctly his probable annual account, which he certainly cannot do when using gas. The mean of the latest three winter months' demands should form in all cases the demand on which to charge the summer consumption, and every consumer should be given the privilege of making one or two unmeasured demands per month and of having an excess demand alarum fixed on his premises on his agreeing to pay an extra rental for same.

The equity and administrative economy of only having one tariff.

In the case of power users and other consumers who are likely or willing to make their demands during the daytime or after ten in the evening, greater than during the early hours of evening, a demand indicator time cut-out should be supplied and an additional rental charged.

In the case of motors, the demand actually recorded is the equivalent of one which must be maintained for an hour. In practice the registered demand may be taken to be roughly the measure of the mean power taken by a motor during the hours it has been most heavily loaded.

It is difficult to imagine any class of consumers who will be unfairly treated by the above tariff or any desirable classes that cannot be sufficiently encouraged by it.

It must not be forgotten that there is considerable administrative economy in having one rigid tariff which does away with all bargaining and disputes, as in such case the whole of the onus of deciding the proper amount of a consumer's bill is borne by a simple instrument whose record can be checked and whose upkeep is much less than that of the staff of clerks necessitated by an elastic schedule of rates.

The system of measuring the actual demands of consumers is of great use to the Distribution Superintendents

It may be here pointed out that the demand indicator involves a greater saving of time in the office than expenditure of time among the meter readers; it enables the distribution Superintendent to have a very accurate knowledge of the maximum load on his mains and enables a very perfect balance to be kept on 3 wire systems.

Opposition to the use of a high initial rate will come from the unprofitable consumers or from an ignorance of its real effect in lowering average costs and charges.

It is often objected that the charging of the high initial rate suggested will provoke great opposition, but it must be remembered that such opposition will only come either from those who now claim to be supplied at a loss, or from those who have not had the effect of the tariff in reducing their accounts properly explained to them. The former objectors are generally those early closing business establishments which can very well afford to pay the supply authorities at least the bare cost of giving them a supply.

All the disadvantages of the uniform rate system apply to the lowering of the initial price and the giving of an optional flat rate.

While permission cannot yet be obtained to raise the initial charge from the present maximum of 8d. no sufficient reason can be adduced for charging a lower figure, or for not maintaining it for the requisite number of hours per annum. All the arguments which have been given against a uniform rate system of charging apply nearly to the same degree to the very common tendency of municipal authorities either to lower the initial price charged on a Hopkinson tariff below the maximum price allowed in their order, or to adopt the equally unsound practice of giving consumers the option of paying on a flat rate, should the differential one make their accounts too heavy. Both practices must, as previously explained, unnecessarily raise the price to the average artificial light user and render it more difficult for the supply authority to obtain his custom.

The Load Factor has only to be increased by unity to cover extra annual cost of Demand Indicators.

It has been suggested that the extra cost and loss of energy in having demand indicators installed on all consumers' premises is sufficiently great to counteract all their theoretical advantages, but as there are now many forms of combined instruments in the market which are neither more expensive nor extravagant in electrical losses than many of the electricity meters at present used, this objection falls to the ground. Moreover, it can be shown that the *general load factor has only to be increased by unity* for the extra profit thereby made to suffice more than to cover the increased annual expenditure the use of demand indicators may involve.

The Wiring Problem ought to be considered on similar principles to those governing the profitable use of Electric Plant.

The wiring problem will undoubtedly have to be energetically attacked if electric lighting is to develop rapidly among the masses, and in the case of municipalities it must be recognised that the same principles govern the profitable use of a supply authority's capital inside the houses as outside them.

The fallacy of charging for the use of Wiring by an addition to the charge per unit consumed.

Nothing could be more injurious to the interests of a supply authority than to make an additional uniform charge per unit for the use of the wiring. The charge should obviously be independent of its use or only the wiring of long used lamps should be undertaken. To charge so much per unit for the use of the wiring is directly to encourage the installation of poor load-factor lamps and discourage good load-factor ones. As the number of lamps wired is generally in excess of the actual number demanded, it is obvious that a charge based on the number demanded is also wrong. In the judgment of the writer the sound method is to offer either to wire only long used lamps or to make an inclusive rental of so much per lamp per annum coupled with a low charge per unit consumed, the difference between the lamps wired and the lamps demanded to be credited at the rate of say 15s. per 16-c.p. lamp per annum, or whatever the tariff may determine, the lamp rental to be diminished after the first four years when the wiring has been paid for. Supply companies have not hitherto seriously undertaken this branch of distribution, but it is just as important and justifiable as the running of distributing mains in promising districts, and the laying of house service connections. Supply Authorities do not object to speculate in the way of the laying of irremovable house services, but hesitate in extending

their mains up to the lamps on the ground that it is putting money on private property; but with a tariff which can compete with gas, surely the risk of idle wiring is no more than that of idle services, which in practice amount to merely 5 per cent. of those laid. Moreover, the Electric Lighting Acts protect already the supply authorities' wiring against seizure or damage.

The curve IX., showing the proper inclusive charge per lamp per annum at Brighton, demonstrates the possible aid which this way of tackling the problem may bring to the supply authorities. Wiring firms cannot be expected to give much assistance in this matter of loan wiring, as they are not so much interested in getting an increased consumption for the supply authorities as in selling expensive fittings; but if they were given a substantial interest in the first year's consumption, their valuable aid would doubtless be forthcoming.

Proper way of getting the real co-operation of the wiring Contractors.

In discussing this tariff question, it is often argued that as the supply authority has had to put down a great deal of capital long before it can be used, it is commercially sound to fill the plant up with business as quickly as possible, without reference to the load factor of the business so obtained, but this implies either an extravagant initial capital expenditure, or a want of faith in the future expansion of the business, or both. If the scheme be properly laid out from the first, proper provision for repeated extensions made, and an encouraging tariff adopted, no fear need be entertained on account of the capital invested remaining unproductive for one or two years, because such loss of interest is much less than the loss which ensues from taking unprofitable business during the early years of the undertaking, which cannot easily be got rid of later on.

Fallacious argument used to justify loading up the Power Stations Plant irrespective of probable Load Factor.

Before concluding this very long paper, I desire to acknowledge my great indebtedness to many engineers and commercial experts for their valuable criticisms of my often crude ideas on the subject of Electricity Tariffs. Particularly am I indebted to Messrs. Henry R. Beeton, W. A. Chamen, J. R. Dick, W. L. Madgen, W. C. P. Tapper, P. Tuckett, and, above all, to my late friend, Mr. Henry Reason, who did more than any other worker on the subject, to drive home the fundamental truths of the Hopkinson theory, both by reason of his forcible and charming eloquence

and by his great manufacturing skill in developing a simple means of carrying the theory into practice.

The President.

The PRESIDENT: Mr. Wright has given us a paper on a most interesting subject, and he has treated it, as he always does, in a most complete manner; in fact, there is nobody who is better fitted to write on this subject than Mr. Wright. Not only has he bestowed a great deal of thought upon it, but his paper bristles with suggestions for discussion. No doubt the question of wiring is of great importance with regard to the extension of electric light in what may be called something less than middle-class residences. The cost of wiring small houses or small villas is one that very often interferes with those who would like to have the light if they could only get over that difficulty; and I think that lies entirely at the root of the great extension of electric light in a most profitable quarter. Those houses would, as Mr. Wright has pointed out, make use of the light much more regularly, having regard to the number of lights, than is the case with lights installed in larger houses.

Mr. Dawbarn.

Mr. R. A. DAWBARN: This subject is one in which I have always taken great interest from the early days when Dr. Hopkinson first introduced into Manchester the system of basing the charge on the number of lights in the premises connected with the mains—a system which in some respects is the basis, I suppose, of the Wright indicator system. There are one or two points which have interested me especially in this paper, and particularly diagram 10 on p. 475. It is interesting because it shows that notwithstanding this very intricate method of charging, it is not perfect and does not really satisfy all the conditions that are to be met with. Mr. Wright does not go quite far enough and tell us how he would really deal with those extreme cases which represent quite an appreciable portion of the total consumption in the case which he brings forward, viz., Brighton.

There is another point which I do not understand very clearly on p. 484. He says: "It has been suggested that the extra cost and loss of energy in having demand indicators installed on all consumers' premises is sufficiently great to counteract all their theoretical advantages," and he then goes on to say that combined instruments are to be obtained which, if I understand him correctly, do not consume anything more in energy, and do not cost any more in first capital cost than do many forms of electricity meter. But the rest of the paragraph seems to me to put rather a different complexion on the case, because, as I understand it, he admits there that the cost (I suppose that includes the interest on capital outlay) of attending to these instruments corresponds to the profits that would be made on a 1 per cent. increase in the load factor. If that is so it is quite clear that one does not use the demand indicator for nothing, and the community as a whole must suffer by the introduction of additional, in itself non-productive, apparatus. Is there no other way of getting over the difficulties that he draws attention to? It appears to me that, as time goes on, and we get electric lighting representing a much larger proportion of the total

artificial lighting, that the demand-indicator system will become less and less important. Take a case where there is no other artificial illuminant than electricity available—there are many abroad, but, of course, not many in this country. I would like to ask Mr. Wright how, under those conditions, he would argue that he has increased his load factor or derived any benefit corresponding to the increased total cost of running such an installation with demand indicators? [Mr. WRIGHT: They always have paraffin.] Yes, and candles. Of course you can always find them if you look for them, but they do not represent any appreciable proportion in many cities. However, the point I was arriving at was whether there was not some way of meeting the worst features of a uniform tariff. I have shown that the Wright demand-indicator system does not really perfectly meet the conditions as shown by Mr. Wright's diagram, No. 10. Assume, for instance, that every one present has his residence lit electrically. We do not want to differentiate between the charges to any two gentlemen in this room, beyond what will be covered by a uniform rate; but that, of course, is not the case when you get to vastly different uses for the light; and it appears to me that it is only in the extreme cases, where the very long-hour users are concerned, that it is necessary to adopt this system. In order to catch say 5 or 10 per cent.—those exceptional users—it should not be necessary, and is not, I submit, advisable to introduce this special apparatus into the installations of the other 90 per cent. The case becomes very pronounced in some of the residential districts in the neighbourhood of London, where the bulk of the users are residential, and all the consumers are more or less of one type. The method that my firm has devised to meet with a case of this kind was embodied in the Foots Cray Provisional Order last year, and it is this: First, a flat rate, the usual minimum being 20 units; and, secondly, at the consumer's option, he may be charged for any amount up to an average of 4½ units per lamp fixed per quarter. That, at the rate of 8d. per unit, is 3s. per quarter per lamp fixed, or 12s. per annum. He, therefore, takes the courage of his convictions that he is a long-hour consumer, and he commits himself beforehand to pay that amount, and then gets his rebate on anything that he consumes over that. We expect this will result in only a few applications, and that it will not be necessary to introduce the instrument into the other consumers' premises, but only into those where they really greatly want it. Mr. Dawbarn

Mr. J. S. HIGHFIELD: It seems to me that all Mr. Wright's contentions are correct, that the business of a central station engineer is to obtain every possible class of load which he can acquire, and to do that it is necessary to adopt some system of differential tariff. Mr. Wright has set very clearly before us the principles of the Hopkinson system of charging, and we all know the way in which he applies that system in practice. In my own station I do not use the demand-indicator system for charging for the lighting, the real reason being that when I took charge of the station a flat rate was in force of 6d. per unit. In a small town in the Midlands, with which I was connected, we used the demand-indicator system, and the great practical difficulty with Mr. Highfield.

Mr. Highfield.

it was to explain the theory of the system to the consumer. The ordinary consumer, we found, was not able to appreciate the difference between his load, which did not give him a reduction, and his neighbour's load, which obtained a very considerable reduction. As a matter of fact, to show that is a very real difficulty, in that town the opposition was so strong that a flat rate of 5d. was given as an alternative to 7d. for the first hour's use of the demand, and 3d. for the extra use. Although I daresay 25 per cent., or even 30 per cent., of the consumers were paying considerably less than 5d. for their current on the old rate, all except two preferred to take the current at 5d.

Now, another point it seems to me is that this system which Mr. Wright explains, operates against the short-hour shop load—the early-closing shop load. The early-closing shopkeepers have to pay a very long price for their current, a price very greatly in excess of what they pay for gas. In a town of the class of Brighton, where the shops are large and the business is great, there probably is not much difficulty about getting a large price; but in a small town where the shops and the businesses are small, it is impossible to charge the price of 7d. per unit, that is to say in any shops in which there is no reduction. Therefore, if it were possible, I should rather have a lower initial price kept on for, say, two hours a day instead of a higher price for one hour. I am quite aware that it is not correct theoretically, and that Mr. Wright's contentions are true, but in a small town with a poor class of people it seems to me that there would be less trouble with the consumers in adopting that system—and, after all, that is the great point.

Mr. Wright has mentioned that the use of batteries might alter the case to some extent. Now, it seems to me that Mr. Wright's way of getting at the initial price is to take the whole of his standing charges, the charges really necessary for the preparation costs, and to take the whole sum and divide it by the total of the individual maximum demands. If by the use of batteries the capital can be reduced—and it can in certain cases—then it will simply bring the initial price per unit a little way down, so that the use of the battery makes an automatic reduction in the particular case which he explains. In a town of the nature of St. Helen's a very great part of the load is for private motor purposes. In the same time more units are sold for such motors than are sold for lighting, and there is also a tramway load. The diversity-factor of such a load is very large, and therefore the total of the consumers' maxima will be very large in comparison with the maximum at the station. That, again, should, it seems to me, enable the initial prices to be reduced. We fixed on 4½d. for lighting, and I for one, at any rate for the present, cannot see any chance of adopting a demand-indicator system. But I may say that my chief object—as I think was the case with the engineer of Montreal—was to encourage the motor load, and we have adopted the demand-indicator system for that load.

All along in electric supply, especially in those towns chiefly composed of small business people, you have the bogey of gas in front

Mr. Highfield.

of you, and gas is always quoted against you—that gas engines can drive a given load at a lower price than motors, and so on—and we have found that for ordinary motor work about 2d. per unit is absolutely the maximum price that can be charged for users who average perhaps only one hour or, at the most, two hours as their maximum demand daily. In taking out gas engines and replacing them with motors we have found that at 2d. per unit the price works out at very much the same rate as with gas, but as soon as we get any load that lasts over two hours a day, then electricity has a less chance as the duration of the demand increases, and it is necessary to make a reduction. This system comes in very well, and as we started with 2d. and were enabled to reduce to a lower rent, viz., for two hours a day 2d., and 1d. after that, our consumers entirely fell in with the arrangement without the slightest trouble. Now at that rate we can more easily compete with the gas, but even that rate is not low enough to compete with 2s. gas under all conditions. I think the great thing for all station engineers to keep in view is to obtain the greatest diversity of load possible, and the best way to do that is to get a large motor load.

There is one other thing I should say about the shop load: as Mr. Wright says, in the early stages of an undertaking, the early-closing shops come on with great readiness. It seems to me that these early-closing shops, although their load is a poor one in ordinary cases, are most excellent advertisements, and for that reason alone they really should have a certain amount of consideration. If any engineer is in such a position that his undertaking has been operating for eight or ten years, and can say to these early-closing shops which are an unprofitable load, "Either remove your load, or else pay double what you now pay," he is in an enviable position. I think the advertising value of very big shops is of great benefit to the undertaking. It not only brings electric lighting prominently, and very early, before the public, but it also induces the authorities to go in for greatly improved street lighting, because when the shop load is turned off, which it is at an early hour of the night, it is necessary to have very good street lighting to keep up the standard of illumination.

The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members:

Alexander James Ewing.	Harry Lorimer Riseley.
Frank L. Monkhouse.	John Woodside.

Associates:

Clarence Edgar Allen.	John Spence.

The Three Hundred and Sixty-Ninth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, December 19th, 1901—Major P. CARDEW, R.E. (Vice-President), in the Chair.

The CHAIRMAN: I regret to have to announce that our President is unavoidably absent to-night on account of the results of the recent blizzard. He has asked me if I would represent him, and to the best of my ability I have consented to do so.

The minutes of the Ordinary General Meeting held on December 12th, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended in the Library.

Messrs. S. Joyce and F. Rawlings were appointed scrutineers of the ballot for the election of new members.

The CHAIRMAN: I have to announce a donation to the Institution of a very striking portrait of her late Majesty, Queen Victoria. The original, of which the picture is a photograph, is by Angeli, and is at Windsor. Major-General Webber, who has presented the photograph, states that it was taken for Her Majesty, that fifty copies were made for her, and given by her to relations and friends; and that no other copies have been made since 1899. The King has lately given special permission to Major-General Webber to have one for presentation to the Institution of Electrical Engineers. I ask you to accord a vote of thanks by acclamation to General Webber for this donation.

The vote was carried by acclamation.

The CHAIRMAN: I have with great regret to announce the death of a very old member, Mr. Matthew Gray, of Silvertown, with whose name I am sure most of you are familiar, and whose work we have long recognised as being of great value.

Resumption of discussion of paper on "SOME PRINCIPLES UNDERLYING THE PROFITABLE SALE OF ELECTRICITY," by ARTHUR WRIGHT, Associate Member.

Mr. Patchell. Mr. W. H. PATCHELL: The first thing that struck me on looking into Mr. Wright's paper, was the great elasticity there is in our profession if men really do hold the views set forth by Mr. Wright on pages 445–447. A man engaged in central-station work ought soon

Mr. Patchell.

to know how he can supply electrical energy and at what rates; but it surprises one to know on Mr. Wright's authority that men can hold such divergent views, because some of them are so diametrically opposed to anything we meet with in London that they take one's breath away. The creed that Mr. Wright preaches to us is an ideal one, but, to speak candidly, I am one of those who have not reached this ideal. If we were in the fortunate position of the reader of the paper, and had a monopoly, we might then be able to dictate terms to the consumers; but our experience in London is that there are

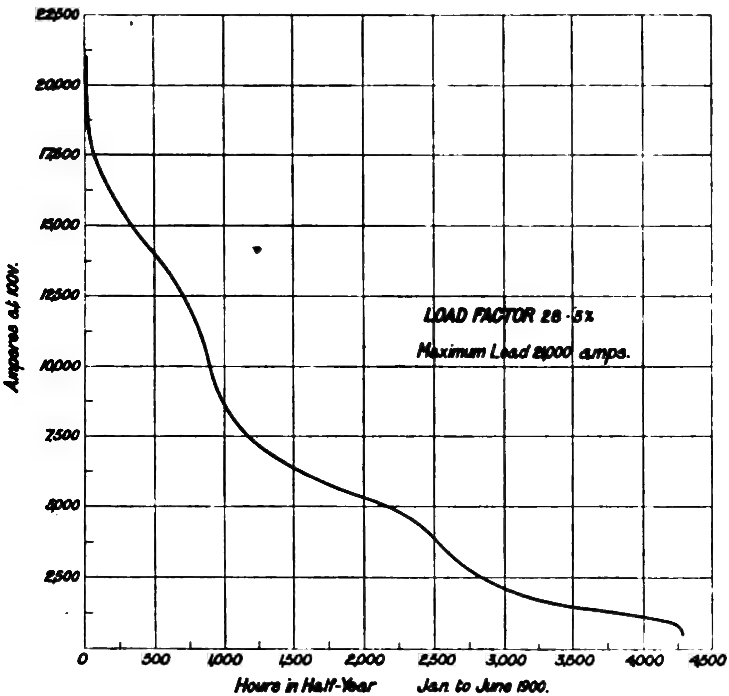


FIG. A.

competing companies against us, sometimes two and always one, so that if we arrange for a satisfactory rate, the rival company immediately quotes a lower price. Then again people are, in many cases, strongly opposed to these methods. They wish to know what they will have to pay; they will pay it willingly, but they must know what their liability will be. If you explain to a man that his rate will start at 8d. and will, under certain conditions, come down to 2d., it does not interest him so much as if you tell him that he is going to pay 4d. or 5d. at an average rate.

Much of Mr. Wright's paper centres round page 461. He there says that if we can get up our load factor we can make money, and if

Mr. Patchell.

we work on a low load factor we lose money. In my Company we have no Wright demand-indicator, but my assistant, Mr. Mayson, has been good enough to calculate out my figures for half a year. Mr. Wright, on page 461, says it can be done by mechanically adding together the number of hours; but it is by no means so simple as it appears. Mr. Mayson has, however, taken these figures out for me, and I have great pleasure in handing them in (see Fig. A). The substance of them is this. Mr. Wright on page 462 gives us three curves. His Brighton load factor was 13; in 1900, by the use of the demand-indicator, it was brought up to 18·76. Stepney, starting as a new concern, presents very abnormal figures. There it is 21; and of course that is solely due to the use of the Wright demand-indicator. But it must also be remembered that the undertaking is run without competition. He can dictate his terms, and people have to take the demand-indicator whether they like it or not. It is also down in the East End, where people rise early and shop late, so that the average lighting hours are much longer than in the West End or in Central London. In Charing Cross for the half year, from January to June 1900, we had a load factor of 28½ without a demand-indicator. I know I shall meet with the rejoinder that if we had 28½ without the instrument, what should we have had with it?

Mr. Wright, at the bottom of page 461, says, "It must be obvious that all the peak of a curve should be supplied from plant put down, having in view rather the lowness of capital costs." There I am with him entirely. I have been trying to live up to that for many years. When we started the Lambeth station my idea was to put down a very high-class plant condensing for the bulk of the load and to run the peak of the load non-condensing, because I did not think we should get our money back for a condenser. That did not come off as soon as we expected, because we got hold of the wrong sort of condenser, but we have succeeded at last, and lately we have been running 75 per cent. of our load condensing, and the effect of that on the coal bill has been very satisfactory. When 75 per cent. of the output is obtained from condensing plant, one can afford to waste a little on the other remaining 25 per cent. We must of course arrange for our plant to be as uniform as possible, but we need not adopt excessive refinements and try to save money on plant which only works for a few hours in the day or sometimes a few hours in the year. Then on page 477 the author refers to power used for motive power and to that for lighting purposes. Naturally all of us who have not a demand-indicator say we will give a man power load or we will give him lighting load, under the belief that he will use his power supply for longer hours. Very often we get hit by it, but that is one of the misfortunes of the business; and until we can live up to these ideals and have Wright demand-indicators for restaurants and railway trains which run empty in the middle of the day, and probably for the telegraph service, we shall have to live by the average; and at the present time, as I say, we can live by a 28½ per cent. load factor on the average.

Mr Mordey.

Mr. W. M. Mordey: I am glad that Mr. Wright has brought this

subject before this Institution, and am sure he has done so in order to have it discussed as thoroughly as possible, without any thought whatever to interests of his own or other people's in the matter. If I express some views that are not quite in accord with his I hope he will take them as coming from one who is very willing to learn. Every line of the paper requires careful thought and the weighing of many things before the arguments can be followed thoroughly. I am afraid many people are entirely incapable of following some of the arguments. The other day I was asked by a University man, a good mathematician, who is in a position of authority in a large institution in the East End, to explain the system to him. He said he had been prevented from putting electric light into his institution because he could not understand what he would have to pay, and therefore they were going on at present with gas. Mr. Highfield gave us as an example last week the fact that the consumers in his town, with one or two exceptions, preferred a simple plan which they understood rather than a complicated one which they could not understand, even if they had to pay more. It is undoubtedly a very great defect in the application of systems of this sort that it is difficult to get ordinary people, unless very skilled in figures, to understand them. Indeed, Mr. Wright himself has said that even persons who are skilled in figures—accountants, and so on—find a difficulty in following the arguments. If that is the case with chartered accountants, I think ordinary people may be forgiven. Mr. Mordey.

It seems to be generally taken for granted that these maximum demand methods are quite sound in principle—that it is only as to the applications that any question can arise. But are we quite sure that all the bases of this system are sound? To illustrate the main basis of this system take, for instance, the case of churches. The idea is put forward that as churches use their lights only for a very short time in the week they ought to pay at a high rate. The theory in this case, and indeed underlying the whole demand system, is that a consumer has installed in the central station a certain amount of plant which is allocated, as it were, to his installation, and that if he is only going to use it for a short time he should pay a higher price. As so put it sounds right. But is it not a fact that when we go to church we generally turn out two or three lamps at home for every one that is turned on in church, and that the load on the station is not greater then, but may very possibly in some cases be less—if there is a good church-going population—than when there is no church on. Or take the case of ball-rooms. I am told that in some cases there are houses where there are hundreds of lights, in large ball-rooms and places of that sort, that are only used once or twice a year, and that the station must keep a supply of power ready to run those lamps whenever there is a ball. But I think it is probable that the same argument applies there as in the case of the churches. When people go to balls their own houses are not lighted as much as usual, and the demand on the station may really be less or not greater when a ball is on than when it is not. Actual results in such cases would be very useful. There must be many instances that have presented themselves to central station engineers, and they can tell us from experience what the effect is in

Mr. Mordey. such a case as that. Is not the whole argument admitted to be wrong by the fact—I am told it is a fact—that customers who have exceptional demands are told by the central station people who use the demand indicator system that if notice is given when the lights are to be used, they will short-circuit their demand indicator for that evening? If that is the case it strikes me—I am only asking for information as a person who is not even an accountant—that it is rather giving away the whole case. Mr. Wright shows us the gradual increase of his load-factor at Brighton, and puts it down to the use of the demand-indicator system. I doubt very much whether people's habits are altered very much by the fact that they have a demand indicator in their houses. The growth of the load-factor at Brighton may possibly, to some extent, be due to the careful way in which this system has been applied there, to the picking and choosing of customers, and so on; but is it not a fact that the load-factor in most places has grown and that in Brighton it would also have grown—possibly not as much, but to some considerable amount—even if the people had been supplied on a simple flat rate. One objection to the system is that it tends to prevent the installation of lights in places in the houses that are not often used—spare bedrooms and places of that sort. A man may have his house filled with guests once or twice a year, and would like to have electric lights all over his house, but he does not put them in because he has a demand-indicator system. It surely must tell against the installation engineer, and it must tell against the use of electric light, in the way that gives the greatest convenience. After all the object of this system is to get at an average. If we can only get at an average we have got at a flat rate. If we have got at a flat rate we may as well charge a flat rate, at any rate for the large proportion of persons who, as Mr. Dawbaarn pointed out last week, probably come fairly within that average. The whole of the customers in a town ought not to be penalised because a small proportion of them require exceptional treatment in the matter of rates. It is not a small matter, this installing of additional non-productive apparatus in every house throughout a town. I do not say there is no advantage gained; there may be some, but is it worth the cost and the trouble and the loss of pressure? I think we ought, as far as possible, to try and reduce to a minimum the non-productive plant that has to be put in. We should keep down the auxiliaries which make the cost of getting into a house considerable. Most supply undertakings are now going down in the social scale in getting customers. Although these additional things may not be a very serious tax on large installations, when you come to cottages and small places the fittings, the main switch, the fuse, the meter, the demand indicator, and possibly a time switch for certain cases, as Mr. Wright proposes, sum up to a good deal in the whole place. They particularly tell against the spread and cheapening of electric light amongst smaller users. It may easily happen that several years' profit may be swallowed up in this way. For instance, the total revenue from a cottage using a few lamps may be only a very few pounds a year. The cost of the additional apparatus may be from one to three pounds, which is a large proportion of one year's revenue and a much larger proportion of the profit. It may

swallow up several years' profit. Mr. Wright refers to the losses in the demand indicator as not greater than those in the meter. But they are additive—and in any case the losses in the meter are great enough in all conscience. When we remember that the thing we really ought to be selling is light—and that the light varies about inversely as the cube of the pressure—a difference of one or two or three per cent. in the pressure makes more difference in the light supplied to the customer than is paid for by any saving effected. I will not take up your time by alluding to anomalies that have been mentioned, which to some extent other speakers have touched upon, but I think that if Mr. Wright proves his case in this matter, our methods of charging for commodities ought to be altered. For example, when we take a railway journey we ought to pay a shilling for going on the platform and a farthing a mile afterwards. For my part I cannot help feeling that simplest ways are best—simplicity of apparatus and of method of charging is what we ought to aim at—the minimum of auxiliary apparatus; and we ought, if possible, to keep for the exceptional customer the exceptional apparatus. Mr. Mordey.

(*Added February* 4, 1902.)

Since the discussion on Mr. Wright's paper I have examined the published returns of the British electric supply undertakings in order to compare the working results of the stations using the demand system with those of the flat-rate stations.

The result is given below in the form of averages of the essential quantities worked out from the very full and useful *Lightning* tables—they are from the paper published on December 26, 1901:—

	Flat Rate.	Demand System.
Number of Stations	34	98
Average Units sold	1,217,076	1,266,287
" Load-factor	12·02	11·65
" Works cost per Unit	2·62d.	2·62d.
" Units sold per lamp	16·8	18·98
" price obtained for private lighting ...	4·56d.	4·52d.
" " " public lighting ...	2·35d.	2·475d.
Companies—Metropolitan	4	9
Provincial	10	21
Local Authorities—Metropolitan	0	6
Provincial	20	62

If the flat rate had the ill effects ascribed to it, it should be shown—as compared with the demand system—in a lower load-factor, a higher works cost per unit, and a higher average price both to private consumers and for public lighting. So far from this being the case the table shows that the average flat-rate load-factor is distinctly higher—that in the works costs there is no difference, that the average prices to private consumers are substantially the same, but that the flat-rate stations are able to supply their public lighting at a lower price than the demand-system stations.

In the "units sold per lamp" the consumer suffers in the one

Mr. Mordey. respect under the demand system, as is to be expected: he uses more energy per lamp. This simply means, so far as I understand it, that, unlike the flat-rate consumer, he has not the convenience of a choice of lamps which he can turn on or off as he wants them. He restricts the number of lamps and uses those he has for a longer time per lamp. This is no advantage to anybody. The table shows that it does not help the station by raising the load-factor, or by giving a lower works cost—it does not help the consumer in the matter of price, for his average price is the same as that of the flat-rate man. It does not help that important body "the trade"—on the contrary—it injures it by restricting the number of lamps installed.

These results are the more significant from the fact that the average size of the stations—as shown by the units sold—is practically the same for the two systems.

In a many-sided question like this it seems safer to rely on the results of a practical working than on arguments, however able-based on statements of principles. The difficulty with the principles is not that they are wrong, but that it has not been possible to give due weight to all the conditions that occur in practice.

Whatever may be said for the demand system as regards individual cases or exceptional consumers, it appears from these results of practical working in a great variety of towns that neither the consumers as a whole, nor the undertakings as a whole, have anything to gain—while they both have something to lose—by the general use of the maximum demand system.

Mr. Dick. Mr. J. R. Dick: The subject which Mr. Wright has so ably and exhaustively dealt with is not one which is of merely insular interest. Greater attention is being devoted to it year by year in all countries where the economics of central stations are studied, and this has led to prices being based on the principles which Mr. Wright has so clearly laid down in his paper. In this connection England occupies the premier position. It is in very pleasant contrast to the position frequently assigned to England by its critics in connection with other branches of the electrical industry. The rapid progress which has been made by this country in cheapening the supply of electricity, and the superiority of our achievements, are freely acknowledged by our Continental and American critics.

With regard to the main argument of Mr. Wright's paper, I am surprised to find that so many engineers are sceptical as to the soundness of the Hopkinson doctrine. All those who have given earnest thought to the question, and who have even pretended to investigate it, not only in this country but in Continental countries, have arrived at the same general form of equation for the costs, with a corresponding equation in relation to the charges, as Mr. Wright has done. The only question that it seems to me worth while for this meeting to consider is, in what way the load curve of each customer or some quantity proportional to his demand can be measured in order to ascertain the relation which it bears to the aggregate load-curve of the station or to the sum of the maximum demands. I think Mr. Wright has very clearly proved in his paper that one of the best ways

of doing this is to use an indicator which has a sufficient time lag to prevent its recording any intermittent or accidental increase of load, but which will give a reading corresponding to the average steady demand made by a customer on the central station plant. It is obvious that intermittent variations are of absolutely no importance in this connection, and should not be measured, because, on account of the diversity-factor in such cases, they do not appear in the general station load, and no provision has to be made in the matter of extra plant. One of the most appropriate names for the demand-indicator is "The Investment Meter," because, more nearly than any other method or instrument, it tells you what you want to know, viz., the proportion of the investment charges which each consumer has to pay. Mr. Wright has clearly shown that by his method all classes are charged fairly, and none of the custom which is desirable is discouraged. That is a very important point. I observe that he has spent some considerable time in discussing what happens in the case of the half-hour class of users who may have one of those very sluggish demand-indicators installed. He suggests that they might escape having to pay the correct amount due to their investment, but I submit that with the ordinary method on which the tariff would be arranged, *i.e.*, a large price for one hour per day and a smaller price subsequently, these customers would never really come on to the lower price. By hypothesis in no case do they exceed one hour per day for one or two months; and as they have to pay a certain number of units at 7d. or 8d. equivalent to one hour's daily use during the *half-year*, they would never be in danger of getting on to the lower scale. I am not in accord with his suggestion of introducing a new method of central station supply in order to meet this one class—that is to say, the use of a battery during the peak. Obviously also it would be with difficulty applicable to an alternating-current station. The importance of getting such a price from each customer as to cover his share of the standing charges and an adequate return for the capital invested cannot be too strongly insisted upon. You have a very good object-lesson in that respect in the great water-power stations in the North of Italy, where the tariff is usually in the following form. The large factories which take electrical power from the mains are charged at a rental of so much per kilowatt demanded, and no other price is required from them for their consumption. In cases where coal is very cheap or where the running costs are very small some similar system might be adopted; in fact, it would be far more reasonable to have a system of that kind for power-distribution charges than to have a flat rate. I know of one instance in a German electrical power-distribution scheme in Silesia where the following tariffs are adopted: There is a rent-charge made per kilowatt demanded, which includes the whole of the investment charges on the central station, together with 8 or 10 per cent. of profit which is added for the shareholders' dividend. The whole of the units supplied to each customer are sold at absolute cost price, which amounts to about four-tenths of a penny. This is somewhat disadvantageous, because it does not encourage the development of that custom which Mr. Wright has Mr. Dick.

Mr. Dick

indicated in the lower part of diagram 10, where the 6-, 7-, and 8-hour users are a class of people yielding a very much better return on their investment by employment of the Brighton differential tariff than those with a smaller daily consumption. The form of tariff in use in the German station emphasises, however, very strongly the importance of *protecting the capital invested in the undertaking.* I think in a general discussion on this subject too much stress is frequently laid on the consumer's objection to being charged in this way. It is not a matter of the remotest interest to him that the undertaking is a loser by supplying him at a fair price. Naturally enough, he simply wants to get it at the lowest price possible. But to offer a consumer with a bad load-factor an alternative rate in conjunction with a differential tariff is just as sensible as offering to sell an article costing eighteenpence at two alternative prices of 2s. and 1s. Obviously the rate of 1s. would be eagerly accepted. I think, also, there is a tendency to generalise too much from the results of one small central station. During this discussion Mr. Highfield has referred to the little town of Stafford. I think the conclusions to be drawn from a statement of that kind are very weak indeed, because after five years' running they only now sell 200,000 units, and that at a loss of £500. Mr. Wright has justly acknowledged very fully the work of Dr. Hopkinson in connection with the subject which he has brought before us; but we all recognise that it is due to Mr. Wright's great enthusiasm and his work during the past seven years that such progress has been made in this country in the cheapening of electrical supply.

Mr. Boot.

Mr. H. L. P. Boot: In the town I represent we have had at times very nearly all the systems in use. We started with a flat rate, and found it a failure. We then went on to so many units per lamp, for the reason that I objected in regard to the demand-indicator: first, to the extra cost per consumer; secondly, to the repairs and maintenance incidental to its use; thirdly, to the cost of setting it; and, fourthly, to the fact that consumers dispute its accuracy, and consider that the Board of Trade should certify the same. However, in spite of all those difficulties, we finally decided to adopt demand-indicators, simply because of their convenience. It is, in my opinion, the only and the best system at present employed.

I need not dwell on the advantages of the system, they are so fully dealt with by the author; but at the same time I should like to emphasise the fact that he says nothing about the disadvantages, and these, I am sorry to say, in many cases are very serious, and require very great consideration on the part of the engineer. We are doing the consumer a great benefit in adopting the demand-indicator system, but my advice to engineers, so far as their own comfort is concerned, is to leave it alone. Mr. Wright on one page of his paper mentions that the system should be properly explained to each consumer. He is fortunate in having a great number of able assistants, and probably he finds that their time is well occupied in this matter. However, although I may criticise the system, it is simply with the object of trying to attain some other system of charging which will have all the advantages of the demand-indicator system and minimise its disadvantages. It appears

to me that the demand-indicator system does not take account of the hour of the maximum demand, and that is essential. For instance, on page 463 the author gives the analysis of charges to the revenue account for the Brighton electricity undertaking. He shows that the interest and sinking fund on the whole, amount to £18,312, and he charges that entirely to preparation costs; and he reckons that the consumer, no matter at what period of the day he demands his amount of electricity, must pay for that amount. Now it is obvious that if that consumer requires his demand, we will say in the afternoon, or at some time when the maximum demand is not on, although he may only require that demand for half an hour or less, the station will not be put to any further expense whatever, and therefore it will pay very well to charge him a *lower* rate than 7d. for that half-hour. Further, it appears to me that what we want is a meter which will read, perhaps, on the basis of one hour per day, or whatever charge may be arranged, at the higher rate, that hour to be counted only during the time of maximum demand, and to charge at the lower rate during any other time, no matter what the consumer's demand may be at other hours, provided it does not coincide with the period of demand. I am told that there is already an idea of putting that suggestion into practice; that is to say, a time-switch has been devised which will arrange to charge on the more or less antiquated Kapp method. The time-switch will only charge those consumers at that rate during the hours of maximum demand, and if the consumer requires his maximum demand at some time when it does not overlap the electricity works demand he can have it at the cheap rate. It is clear, therefore, that what we want to do is to encourage consumers during all hours except those of the peak. I notice also on page 463 that the charge for coal given in the preparation costs appears to be extremely high compared with the total coal costs. I have taken out my own figures very carefully on a very similar basis, and I cannot get the preparation costs of coal at anything like 50 per cent. of my total costs. So that although admitting that the system is the best, I think the author has made out, I will not say an exaggerated case, but certainly a very strong case for adopting it. I think that some of the figures may be toned down considerably, and I should transfer several items from the second to the first column. It would not affect the case generally, except that it might have the effect of altering the time-factor. **Mr. Boot.**

With regard to diagram 10, I think it is the first time I have ever seen a diagram plotted in that way, although since then I have tried many. Has the author left out any class of consumers? Because it will make all the difference to the demand if a certain class is eradicated from the diagram. I find that the chart for the Tunbridge Wells works gives 1·5 hour daily as the top of the peak; whereas Brighton shows the larger number of consumers burning for two or three hours daily. [Mr. WRIGHT: Five hundred is the number of each class, not the total number on the station, and all our consumers are included in that.] One thing the author mentions is very important, and I do not think it has been generally realised, viz., that the present system of charging for free wiring is a failure in the direction of inducing con-

Mr. Boot. sumers to come on the mains. If you charge a price per unit you will undoubtedly find, as we have found, that it stops consumers putting in lamps or using much electricity by those lamps; it is far better to charge by another method, as the author suggests.

Mr. Aron. Mr. L. J. ARON: Mr. Wright's paper demonstrates the stages through which the electric light industry has advanced. The results at Brighton now placed at our disposal show that our power-station managers have only been having small skirmishes with the outposts of the gas industry, and now Mr. Wright seems to have sounded the battle-cry for a general attack. It may be news to some that a gas company collects over two hundred and forty tons of coppers in one district in the South of London in one period alone, and they have to employ special brokers to get rid of the coppers amongst tradesmen. In dealing with 5- and 6-light consumers, I think Mr. Wright has not laid sufficient stress upon the point that during the three hours that such consumers use their lights, they would generally use nearly all of them; in fact in such small installations all lamps are practically long-hour lamps. In small houses and flats I do not think there is the same tendency to insert a light unless it is absolutely wanted, and if this is so the demand-indicator could be eliminated. I would suggest for consideration elimination with such small consumers of both the maximum demand-indicator and the meter. It need not be feared that such consumers will demand a meter, and it is only when such a meter is asked for that power-station managers are compelled to insert them.

I should suggest utilising a time meter electrically driven on the pre-payment system. Such a meter can be made in the case of a six-light consumer, to register twice as slowly if only three lights or fewer are used. The consumer would have to put in before the end of the quarter the amount corresponding to the annual rent of 7s. per lamp, and, where the installation has been done free of cost, the proportionate payment for the installation. If the collector does not find this money in the box when he calls, together with the necessary number of pence corresponding to the hours the lamps have been used, the light can be immediately disconnected. Such a pre-payment hour meter can be sold considerably cheaper than the demand-indicator with the meter, and it would serve the additional purpose of collecting accounts. It would also have the advantage of consuming practically no power. The consumer who demands a meter can be made to pay the extra cost of its installation until it is paid for. The cost of maintaining the meters seems to me to be one which should be capable of reduction, and it appears that it is undoubtedly the correct principle that the consumer should pay for the cost of maintaining the instruments, if not too heavy.

In dealing with the various other classes of consumers which Mr. Wright has so ably classified, the necessity for permanently installing the maximum demand-indicator does not seem to be proved. In a great number of shops, and certainly in most residential districts, the maximum demand becomes a standard figure, and although this figure cannot be estimated previously, at the end of the year the maximum demand-indicator remains as dead capital to the consumer. In

increases from the corresponding quarter of the previous year, the total amount registered will more generally be due to an increase in the length of hours rather than in the maximum demand. It should not be impracticable to insert the maximum demand-indicator only as a guide to results, and having obtained that guide, to allow it to be removed and used in another consumer's premises. It may be of interest to central-station managers to know that the system I have proposed for the very small consumer is now in daily use in various parts of the Continent, and I believe with considerable success. Mr. Aron.

Another suggestion I should make in substitution of Mr. Wright's proposal to cut out the maximum demand-indicator during the hours of non-peak, which would be an extremely expensive method, as a satisfactory time-switch, such as Mr. Wright speaks of to guide the main circuit, could not be economically produced. A two-rate energy meter, or really a three-rate meter, could be constructed, which would read at one rate on light loads throughout the day; it could then be slowed during the hours of non-peak, on heavy load, and could be made to go faster during the hours of peak with heavy load. This would serve all the purposes for the special consumer to which Mr. Wright refers, but if necessary the demand-indicator could be temporarily inserted to control the mean maximum demand. In a recent correspondence in America on the same subject as is now under discussion, a similar idea was mooted in the *Electrical Times* as being a correct method of solving the difficulty. An instrument could also be economically produced on the two-rate system, but reading hours only.

Mr. Wright's proposal of allowing a consumer one or two unmeasured demands per month seems to me to be an extremely difficult matter to adjust.

Mr. Wright's paper has demonstrated, I think, to the manufacturers the possible requirements of power-station managers, as well as having demonstrated to power-station managers the possible developments which should satiate the appetites of the most ambitious.

I would like to call attention to three other passages in the paper. On page 445 the assumption contained in the second paragraph that the load-factor has been increased owing to the use of the Wright method is illusive; it is not fair to attribute the increase entirely to this, for in nearly every other central station the load-factor improves whether the Wright method is used or not—for instance the St. James's and Pall Mall Co.

Again, to quote (page 446) a higher evening rate and a low day rate can not only have the effect of making the consumer economical with light during the station's heavy load, but does, as a matter of fact, materially increase the number of lamps installed in kitchens, passages, and bedrooms.

Finally, the use of the sluggish indicator has the effect of enabling a large consumer, theatre proprietor for instance, to use a number of lights for sixty minutes every night without affecting his quarterly bill materially, but if he uses it for sixty-one minutes he will have to pay a higher average price for every unit consumed during the quarter, which of course is absurd.

Mr. Andrews.

Mr. L. Andrews: We have had the demand system in use at Hastings for about six years, and after what has been said by a number of speakers you will probably be surprised to hear that we are still in favour of it, but we do not believe in carrying it too far. I myself think it is a mistake to attempt to use demand-indicators for all consumers. There is no doubt we all agree that there are certain consumers we can afford to supply at very much lower rates than others. For instance, people using their lights for five or six hours a day can undoubtedly be supplied at a lower rate than those using lights for only one or two hours a day; but I do not think we ought to go beyond that. We ought not to discriminate between consumers using their lights an hour a day and those using them two hours a day. If you use your demand-indicator only for consumers who use their lights for over two hours

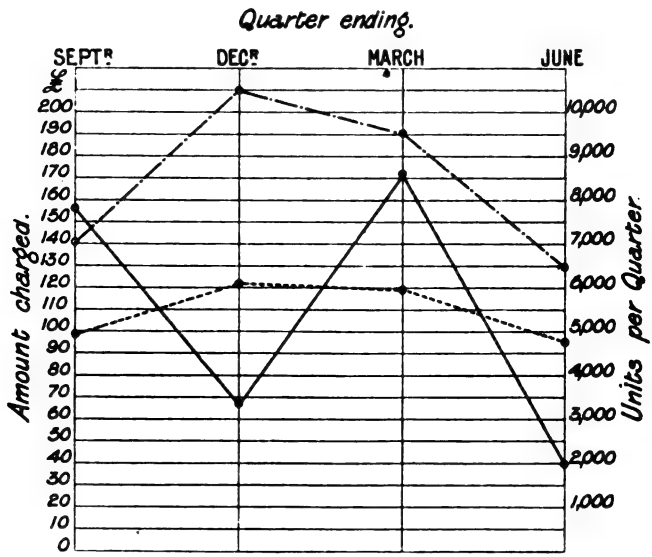


Fig. B.

The Curve (—·—·—) = Units used per quarter.
" " (————) = Quarterly charges under the Brighton system.
" " (............) = Quarterly charges under the Hastings system.

per day, and fix your price so that it will only attract them, you will do away with the expense of having so many demand-indicators. I also think you ought not to attempt to force any demand system upon consumers. My experience is that if you give them the option of a system they will take to it much better.

There is one defect in the Brighton system which I think no speaker has yet touched upon. I referred to it myself in a letter to *Lightning* about five or six years ago, when everybody was thinking of demand-indicators. It is the irregularity of the accounts. The curve —·—· in Fig. B. shows the consumption per quarter of one of our actual consumers at Hastings (for instance, this consumer used about 7,000

units in the September quarter, 10,000 in the December quarter, and so on). Now under the Brighton system, in the September quarter he will be required to pay, perhaps, for half of these units at a high price and will get the remainder at a lower price; the result is he gets a heavy bill for a small consumption, viz., a charge of £155 for 7,000 units. Then in the December quarter he uses more units (10,000 as against 7,000); but he will get them all at the low rate, and, as a consequence, his bill will only come to £68; that is to say, he uses many more units but he only has to pay £68 instead of £150. He naturally thinks that the more units he uses the less his bill comes to; and a great many people who are accustomed to this system of charging actually believe that. Then in the March quarter he uses only 9,000 units, but his bill now comes to £170. The full-line curve (———) shows how the quarterly accounts vary under the Brighton system. Of course, Mr. Wright will say that a consumer gets used to that; but imagine the effect of it on a man who is taking over a business! Supposing the proprietor of this business gives it up at Christmas time; a new proprietor comes in, and he wonders what his lighting bill is going to be. He looks up the previous quarter's bill, sees that it is £68, and thinks if he sets aside £70 he will be all right. When his bill comes in he finds that it amounts to £170, and he is naturally very indignant about it. We found this difficulty after we had had the demand system in use about nine months, commencing in July; the consumers absolutely refused to pay their bills, and my directors said that we must go back to an ordinary flat rate. There were a great many advantages in the demand-indicator system, and I did not like quite giving it up, so I got them to allow me to modify the charge. I pointed out that all we wished to do was to charge every consumer a fair proportion on the interest and sinking fund, on the cost of the plant necessary to supply him, and other stand-by charges. It seemed to be a great mistake to worry consumers with questions of amperes, kilowatts, and varying rates per unit, when it would be very much more simple to charge them at so much per lamp to cover these stand-by charges. Everybody knows what an 8 c.p. lamp is, and if you work out just what your stand-by charges are per lamp you can tell exactly the figure. We find at Hastings, at the present time, our stand-by charges are about 10s. per 8 c.p. lamp, and the cost of current in addition to that is about 1½d. per unit. What we do at Hastings is to announce that our price for current is 6d. per unit, but that if any consumer likes to pay the interest and sinking fund on the capital necessary to supply him, and the other stand-by charges, we will supply him with current at 1½d. a unit. My Committee, who favoured a flat rate, said that I was on no account to endeavour to force this charge, in fact I was to say nothing about the lamp charge. I was merely to say that the charge was sixpence a unit, but that anybody using his lights more than two hours a day might get his current at a reduced rate. People came to me and asked what this lower rate was, and I told them that if they liked to pay 10s. per annum per 8 c.p. lamp in use at any one time, payable in quarterly instalments, they could have as much current as they liked at 1½d. per unit. There was not a

Mr. Andrews.

Mr. Andrews.

single consumer who had the slightest difficulty in understanding it, and during the present year we shall have sold over 400,000 units upon this basis without asking a single person to adopt it. 400,000 units represents about 65 per cent. of our total current. We have a very large number of consumers who use their lights for an hour or two hours a day, and if these people ask about the reduced price I tell them that the system is of no use to them. It is, I think, quite impossible to get the exact cost of supplying consumers. For instance, a four-hour consumer who lives about three miles from our station might cost more per unit to supply than a one-hour consumer within, say, a quarter of a mile. [Professor PERRY : Did you say 10s. a year per lamp ?] Yes. Of course that is very high, but you must remember that the Hastings electric light concern has been going about eighteen years and it is very heavily capitalised, but this charge enables consumers to get their current at 1½d. a unit, and the average price paid by long hour consumers is only 3½d. per unit, which is by no means high. The dotted (.........) curve in Fig. B. shows the amount that the consumer referred to above pays under our present arrangement. It bears some sort of proportion to the current, and does not go up and down like the Brighton curve does, though the total amount paid per annum is exactly the same under the two systems.

Mr. Madgen.

Mr. W. L. MADGEN : Those who have advocated the principle of the maximum demand basis of charging have brought forward distinct evidence in its favour, while the objections to it for the most part have consisted of vague apprehensions. We may take Mr. Mordey as a type of the objectors. He said he did not understand the system, and to that extent I am disposed to agree with him. I propose to give you some information as to what the effect of the form of tariff has actually been upon supply-station results. During the past year I have taken pains to extract from such sources as were available the variation of the load factors from year to year for different electric supply stations, and that evidence has satisfied me that the maximum demand basis of charging is justified by results. As two instances I may quote Portsmouth and South Shields. I cannot give you many examples in the limited time at my disposal, but I may tell you that I am quite satisfied that the maximum demand basis of charging has a marked effect upon the commercial and profitable development of the electricity supply system. In Portsmouth they have since the commencement charged a uniform price; it is now, I think, 4½d. per unit. It is just as well to ignore the load factor during the broken period of the first year, because the business has not usually settled down by that time. The load factor in Portsmouth in 1896–7, the second year of operations, was 14·51 per cent., and it has been steadily getting worse. In 1900–1 it was 12·01, a decrease of no less than 2½, which is, of course, a very serious thing. In South Shields, also a shipping town, where they have steadily adhered to the maximum demand-indicator system since they commenced operations, the load factor in 1898–9 was 10·88. There has been a steady increase each year, and for the period ending March last it was 12·24, an increase of close upon 1½. I will give you two examples from London, which will be sufficient for the present. In

Mr. Madgen.

Islington, where they adopted the maximum demand-indicator system from the commencement, the load factor has increased from 9·82 in 1897 to 15·31 in the period ending March last, an increase of 5½. In St. Pancras they started with a flat rate, and in 1893, the second year of operations, the load factor was 19·74. They adhered to that flat rate until 1896–7, at which period the load factor had decreased from the figure I have mentioned to 11·74, a very marked drop. They then adopted the equitable basis of charging, and the load factor has since shown a steady increase; it is now 15·09. Similar conclusions may be drawn from other examples, but there are variations—Edinburgh, for instance, where they have had a flat rate, and the load factor has been tending slightly to improve, but that may be due to a large access of street lighting, or some other causes. Those of us who have studied the subject in the commercial sense know that the man who uses his maximum demand for the equivalent of only one hour per day throughout the year, who is, in fact, a short-hour user, actually costs 7d. per unit to supply from the average English station. If you have a uniform price and you sell the supply to such as him at 4½d., 5d., or 6d., you are selling a commodity which is in common and increasing demand at something under cost, and the general experience has been in other trades that under these conditions you sell a very great deal of it! The result is you will get a rush of the most unprofitable class of customers that you can well have in a town. You get early-closing shops, offices, and places of that kind, and the more you get the more you lose by them, until presently you come to what I may term a tariff deadlock; that is to say your long-hour consumers, whom upon an equitable tariff you could supply at a lower rate than 4½d., are bearing as much as they can stand of the loss incurred by the short-hour consumers. You cannot decrease the price and you may not raise it; but the difficulty will not cease there, it must soon tell upon the capital account. With those short-hour lamps, attracted rather than discouraged, you can with difficulty provide enough plant to meet the peak which they create; it is a labour of Sisyphus trying to get your plant equal to such steep hills in the load curve.

I feel that in fixing a tariff you have to do so with strict relation to commercial principles. If you are going to sell a commodity, whatever it may be, the price you charge *must* be based on the incidences of the cost of production—that is axiomatic; and I prefer to adhere to such a principle rather than defer to the ignorance and prejudice of certain consumers.

Mr. Minshall.

Mr. T. H. Minshall: I do not wish to discuss the merits of the maximum demand system, because I think any discussion on that subject at the present time is almost as antiquated as a discussion on the advantages of electric light, but I do think that possibly some attention might be directed to the question of its expediency. There is no doubt whatever that this system is an exceedingly unpopular one with consumers, and I have it on good authority that even in Brighton itself it is so. But that is an objection which should not weigh too heavily. The enthusiasm with which the profession has embraced this system indicates that the demand-indicator will have to be put up with.

Mr. Minshall.

Undoubtedly it has the effect of attracting the right class of consumers. We started at Croydon with a flat rate of 6d., with discounts to big consumers. We obtained many shops closing at seven o'clock, and a few public-houses, but no clubs. I found that we were steadily losing practically every long-hour consumer we had. We have in Croydon one of the best gas supplies in the kingdom, the President of the Institution of Gas Engineers being the manager of the gas works. We then went in for the maximum demand system with rates of 7d. and 2d. I am thankful to say that at the time we introduced the maximum demand system we effected a reduction of price. Our average price before was 6d., afterwards it was 4¾d. I do not envy those engineers who have to change over without reduction of price. The few people who have to pay the 7d. give more trouble than all the people who get the 2d. unit. At the present time we charge 7d. and 2d., and give the consumers no option. When we introduced the maximum demand system we made it different from that at Brighton. There were one or two difficulties in that system, and we were foolish enough to think that if we had a system of our own we might make the people understand it. At Brighton and other places the public objected very much to the credit system of carrying over from one quarter to another. We decided to have every quarter on its own basis, and found out what was the proportion of units per lamp. The result is we charge our maximum rate for 1½ hours in the winter and half an hour in the summer; and the average price is about 10 per cent more in the winter. The second modification we adopted was that we had scales put on the demand-indicator with the two rates, one on each side, so that a man could read his units at 7d. without applying to us. The third change we made in order to make the matter perfectly clear, was to issue a new form of account. The old form only did for one year, issuing our accounts for so many units at 7d. and so many at 2d., but there was a great trouble in consequence. The consumers all looked at the 7d. units, and could not see the 2d. units at all. They were all gettting a 20 per cent. reduction, but they did not take that into account. The next year we varied the system. I got out a hyperbolic curve, and worked out all the currents on the average. I then stated on the bills, so many units at the average price, say, 4·2d., and then in very small figures underneath so many units at 7d. and so many at 2d.; and the number of complaining letters fell from 250 a quarter to about fifteen or twenty, simply because I quoted the average price instead of stating the actual figures. We have continued to use this system and our load factor has improved, but it is very difficult to find how much of that is due to the demand-indicator. We have both traction plant, and we also have much public lighting, which assists us materially.

The author has mentioned another most important point. On Diagram 3 he shows that it does not pay to use the most economical plant for the peak. That is a most important thing, because so many engineers in designing stations choose the wrong sort of plant. One man puts in a slow-speed engine with super-heaters; another man sometimes with a very big load factor indeed, perhaps with a traction

load, will put in uneconomical engines, and will not take the trouble to put in super-heaters or economisers. Mr. Wright has shown us when it pays us to put in super-heaters and condensers. This is one of the most useful diagrams which has been submitted. There is a very interesting example at Edinburgh, where a station has been put down for the winter load only. It is a big station where they have no economical plant, no economisers, no condensers, and I do not think they even have super-heaters. They have put a plant down simply to run for the winter, and it would not earn the interest on economical plants. Mr. Minshall.

There is one other point I should like to allude to, as it seems the fashion to mention systems. I had a German meter which I was asked to buy. It had iron inside. We put it on the mains, and we found that this meter went very slowly in the day-time and very fast during the evening. I did not understand why. We looked into it, and we found that in the day-time the load on the mains being practically all transformers, with a few lamps on, we had a very jagged wave-form, but in the evening we had nearly a sine-curve wave, because there was a higher power-factor upon it. The result was the best automatic system I have ever seen.

Mr. HENRY R. BEETON: I had no intention when I came here this evening of speaking, but I have listened with interest and attention to the previous speakers, and from their observations it occurs to me that perhaps electrical engineers do not devote sufficient attention to the commercial aspect of electric lighting. I believe, to use an expression of Mr. Wright himself, that it is much more important to devote attention to securing the efficiency of capital than the efficiency of plant. What we want to do is to promote the success of electric lighting, and to that end we require to sell as much of it as possible, provided always that we sell it at a profit. Now, so far as I have been able to ascertain, the tariff system advocated by Mr. Wright is the one best calculated to secure that result, because it enables us to regulate the price according to the varying cost of production to each consumer. In other words it ensures, in the nature of the tariff itself, that no consumer shall be supplied at a loss, and that all consumers shall be supplied at a reasonable profit, which is, after all, the sound basis upon which all commodities in the ordinary course of competition are sold. I should like further to say that it appears to me to be no objection to the tariff system advocated by Mr. Wright that it is not a perfect system. It is perhaps inconceivable that any system should be perfect, and all we can reasonably expect to find is one which presents comparatively few objections. I confess, however, that I am not able to find much sympathy for the objections which have been urged this evening. One speaker, Mr. Boot, said that he thought the object in view should be to encourage consumers during the light load, which is as much as to say that we should encourage consumers to take electricity when they do not want it. But, surely, a man who went into business with the object of encouraging people to buy a commodity when they did not want it would not be likely to do a good trade. Imagine, for instance, a Mr. Beeton

Mr. Beeton. producer of comestibles who should offer men food after they had dined; and is not the producer who offers electric light during the hours of sunshine in much the same case? Too much has been said this evening, in my judgment, in regard to the need of conciliating the prejudice of the consumer. What, I should like to know, do any of us understand of the rationale of the prices of 90 per cent. of the commodities which we consume? And what need is there that we should? Surely, what we want to do is not to conciliate the prejudice of the public, but to earn the approval of the expert; and if our tariff is sound, if there is a general consensus of opinion that it will stand investigation, that is all that is necessary. One speaker to whom I listened last Thursday said that the great thing was to give the public an intelligible tariff, and that, after all, if some consumers were supplied at a loss it did not matter, because others were supplied at a profit, and that in the long run a flat rate answered very well. His remarks reminded me of the story of one judge happening to meet another on their return from Circuit, and asking the other how the Assizes had gone off. To which the reply was: "Oh, they went off very well; sometimes the verdict was given for the plaintiff when it ought to have been given for the defendant, and sometimes the verdict was given for the defendant when it ought to have been given for the plaintiff, but on the whole justice was done." It is surely no satisfaction whatever to be told that if some people are supplied at a loss others are supplied at a profit, when what is wanted is to encourage consumption by reducing the price to all consumers as far as the cost of production will permit. It is exceedingly difficult to lower the price of electricity to those consumers whose demand entitles them to a reduction with the certain knowledge that the loss at which other consumers are being supplied must be increased by so doing. Therefore it appears to me that if proper consideration is really given to the broad commercial aspects of this tariff system, which is based, as I believe, upon thoroughly sound principles, it will emerge as amongst all others the one best calculated to meet the requirements of the industry.

Mr. Still. Mr. PERCY STILL: I thoroughly agree in principle with the statements of Mr. Wright, especially on the point of the fairness of what he calls the Hopkinson tariff. Mr. Wright throughout very modestly refers to this as the Hopkinson tariff. Of course we know that the principle is due to Dr. Hopkinson, but at the same time, if it had not been for the thorough manner in which Mr. Wright has taken up the question, the system would not have had the practical success it has; and it certainly will be known in the future as the Wright system. The difficulty is, as several other speakers have already mentioned, that the principle can be carried too far in certain cases. I will only give one example, the case of the large early closing shops. In some of the West End districts we have a considerable number of these large business premises which close early, and which use the light perhaps only during six months of the year. Shops closing at about half-past six commence using the light in the month of September, and, after the end of March, or, at any rate, early in the month of April, they cease taking a supply altogether, unless

they have basement lighting. As against that there are frequently in the same district residential houses in fashionable streets and squares, which really only commence to use the supply to any extent after the shops have ceased taking it, that is, as far as the period of the year is concerned, these are the large houses that are only occupied during the London season proper after the end of the month of March, say till the end of June. The principle of this system is that every consumer should pay his proportion of the capital charges before he obtains the units at the second price. In the case just mentioned the large shops have to pay these capital charges first. The same plant and the same buildings are used for supplying another class of customers at another time of the year, and these customers have to pay those capital charges per annum over again. I contend that under these circumstances it is possible to supply this second class of consumers profitably without charging an excessive first price. That is the only point I wish to touch on to-night—the question of a high initial price. I can see no reason why these consumers, who may be bad consumers from the point of view of the hours during which they use the light, cannot be supplied except at a prohibitory price. According to Mr. Wright's arguments, I understand he complains that the highest price which it is possible to charge at present in many cases in England is 8d. In my case we are in the happy position of being able to charge a higher price. Our statutory price is 10d. per unit, but we have not enforced that price yet. I cannot see that it should be necessary to refuse the custom of short-hour consumers, or practically to refuse that custom by placing what would be a prohibitive price upon the supply required by those consumers. Mr. Still.

Mr. REGINALD P. WILSON (*communicated*): The paper, which is an exceedingly interesting one, really resolves itself, so far as the discussion is concerned, into the question of the merits of two different systems—the Maximum Demand System, with which Mr. Wright's name has been so long associated, and the Kapp two-rate system. It is quite conceivable that I have not the same idea as to what this latter system is as Mr. Wright, and, therefore, I should like to preface my remarks by stating that my understanding of the Kapp system is that the registrations of the meter are controlled by a clockwork mechanism of some sort in such a way that the actual number of units consumed during the period of say from 5 to 7 in the evening is registered accurately on the meter, but that only one quarter, or a half, or a third of the actual number of the units consumed is registered on that meter during the remainder of the twenty-two hours a day; that is to say, that during the period of the peak of the load the total number of units consumed is registered, whereas during the period of the day when little or no load is being generated by the station, only a fraction of each of these is registered. Mr. Wilson.

The total number of units ascertained to be registered on the meter at the end of the quarter is then multiplied by the rate to be charged. Thus at Dudley this two-rate system is in use, and the two rates are 6d. for the period of the heavy load and 1½d. for the remainder of the time.

It is the business of all supply authorities to improve the ratio of costs to revenue, and the quickest way to do that is admittedly to use

Mr. Wilson. reliable, as distinct from superlatively efficient, machinery and plant and to get profitable consumers.

As to the definition of what is a profitable consumer, there appears to be some difference of opinion. This difference apparently arises from a desire on Mr. Wright's part to consider them from the standpoint of what might be or ought to be rather than what is.

In the second paragraph on page 455, Mr. Wright says that all consumers ought to be debited with the same proportion of standing-by charges as if all their demands were simultaneous. If you adopt the Maximum Demand System you must assume this, and one cannot help thinking that in Mr. Wright's case the wish was father to the thought. This is a proposition which is to my mind indefensible. What we have to consider is whether in practice a consumer who takes no current between 5 and 8 p.m. actually adds to the total annual costs and, if so, to what extent.

We are all agreed that such a consumer's units actually cost the station something less than a penny for consumable stores, but because, and I venture to say simply because, the Maximum Demand indicator cannot discriminate between day load and peak load, the most profitable consumers are deliberately discouraged and no direct attempt such as the consumer can appreciate is made to prevent the overlapping of the motor and the lighting loads.

The Kapp method does this effectually and presents no complication to the consumer, who can and does understand his position at once. He is told that if he runs his motor between 5 and 7 p.m. he must pay extra for it. On page 477 Mr. Wright charges Mr. Kapp with underrating the value of artificial lighting business, but there is no real difference between Kapp and Wright except that Mr. Wright has to put up with his overlapping loads and professes to like it, whereas, while agreeing with Mr. Wright that artificial lighting at the period of peak is profitable at 8d., Mr. Kapp contends that the absence of overlapping makes it more profitable still.

On page 477 again it is suggested that 8d., if charged by Kapp is a prohibitive price, but there would appear to be no difference between Wright's 8d. and Kapp's. I think this statement must be what Mr. Wright calls a "by-product." To the average consumer the only thing that matters is the average price; in Wright's case this average is based on an imaginary ratio of cost to revenue, in Kapp's the actual ratio is taken as the basis.

I should like to add that I cordially sympathise with Mr. Wright's lamentations on page 455 as to "hazy ideas," but he has omitted one of the haziest. There are some authorities who partially carry out the free wiring as Wright suggests, but do so in such a way as to add to their peak and discourage any other consumption.

There are two companies who have undoubtedly increased their clientele by putting in free wiring for six lamps in selected positions, such as two in the dining-room, three in the drawing-room, and one in the hall. At first sight it would appear that their action is wise because some of them will be long-hour lamps, but in practice it is found that consumers who have had wiring given to them for the principal rooms

will not and do not go to the expense of wiring their other rooms. Mr. Wilson. This system undoubtedly benefits the station to some microscopic extent, and it is conceivable that there may be districts in which the residences are largely composed of small flats where such a system would be very beneficial and would tend to improve the load curve but it altogether misses the most profitable consumer.

The most profitable consumer is the one who takes his supply at the lowest point in the load curve, and Kapp's method as used at Bristol and Dudley offers him more encouragement than Wright's, because to take an extreme case of two consumers charged, say, 7d. and a 1d., each taking one hour's supply at eleven o'clock in the day, the Brighton consumer pays 7d. per unit and the Dudley consumer pays 1d. per unit, although these consumers are the very ones Mr. Wright aims to get at as they contribute to the increase of the diversity factor, but in the case of all consumers who contribute to the diversity factor the Brighton average must be higher than the Dudley average, and as already stated it is the average price that the consumer thinks about.

The Maximum Demand Indicator method is admittedly very complicated, and is surrounded by a halo of mystery and mathematics (see page 481). I think we should all like to hear Professor Kennedy's views on the subject, as in spite of his having originally suggested the use of something in the nature of a Maximum Demand Indicator, he does not adopt it, but commits some of the enormities which rouse Mr. Wright's righteous indignation.

The price of every commodity except gold is governed by the ratio of supply and demand, and I think the same should apply to electricity supplied at Brighton. I think also that if Mr. Wright will look upon the question from this point of view, he will agree that there is some force in this contention. If his theory were correct, the coal merchant would be justified in charging him for coals at a price based on the assumption that his demand for coal is created at the period of the peak, or, in other words, when coal is at its highest price; and I think if we applied this argument to Mr. Wright himself, he would quite see that there is no justification for his statement that he is entitled to buy coals on terms which differ from the conditions under which he is prepared to sell what he makes out of his coals.

Mr. Wright on page 483 says: "It must not be forgotten that there is considerable administrative economy in having one rigid tariff." I am inclined to think that anybody who has once used the Maximum Demand Indicator is never likely to forget that. He further on infers that the system in question involves a staff of clerks, and there is no doubt in my mind that it not only involves clerks, but they must be capable mathematicians; in fact, I have heard it stated that the principal difficulty in the introduction of a Maximum Demand System of charging is that the majority of consumers have not been in their earlier youth educated in the differential calculus.

Mr. L. H. HORDERN (*communicated*): Some years ago I had a Mr. Hordern. controversy with Mr. Wright on the subject he has brought before us, and I am glad to see he now admits a third column in his distribution

Mr. Hordern.

of costs—the charge "per consumer," and this allows that a small consumer costs more to supply than does a large one.

Mr. Wright states his case very fully, but the gist of it is contained in his analysis of the Brighton accounts, and the soundness or otherwise of his views depends on whether the items mentioned in column 2 are fairly divisible amongst consumers in proportion to their maximum demands. Now throughout his paper Mr. Wright assumes this proportion to be true; he does not once attempt to prove it, while he shows that there are many cases where it is not even approximately correct. Some two-thirds of the total in this column is made up of charges connected with capital, or with maintaining in working order the various items on which capital has been spent. I include in this interest and sinking fund, rates, taxes, insurance, legal expenses, and repairs to buildings, mains, and plant. Mr. Wright considers that these are not divisible either per unit or per consumer, but he does not show by what process he arrives at the conclusion that they are fairly divisible per k.w. of consumer's maximum demand.

Take the one item of capital expenditure, which of all others we should expect to find in this proportion, viz., plant. Mr. Wright admits that consumers' maximum demands are not all made at the same time, and he suggests various ingenious devices for getting over the difficulty, but the mere fact that such devices are required seems fatal to his assumption. The demands of individual consumers, at the time of greatest call on the plant, may be anything from 0 per cent. to 100 per cent. of their maximum demands. Whole classes can be shown to vary from at least 70 per cent. to 100 per cent, depending on the proportion of each supplied. So that the maximum demand of an individual is clearly no criterion of the proportion of plant he obliges us to install. Land and buildings, again, depend, or should depend, not only on the needs of the moment but partly on the anticipated requirements of future consumers. The cost of mains—one of the largest items—is different for every consumer. It has scarcely anything to do with his demand, but depends principally on his position. The cost of meters, as Mr. Wright admits, is proportional per consumer, and the preliminary expenses cannot be apportioned per kilowatt.

For Mr. Wright's system to work fairly he must prove that the capital costs of an undertaking are strictly divisible amongst the several consumers in proportion to their maximum demand. This he has not done yet.

When talking of comparing one station with another Mr. Wright says: "Capital costs, being roughly in proportion to the maximum load provided for, the length of streets supplied with distributing mains, and the number of consumers connected cannot be properly calculated solely on the basis either of units sold or on the maximum load in kilowatts with which they have no simple relation."

I maintain that this is equally true when comparing different parts of an area supplied from one station, or one consumer with another, and that the best way to deal with capital costs is to charge them as a percentage on the total working costs, the only practicable way to do which is by means of a discount to large consumers.

There are other items in the analysis of the Brighton accounts which I think should be differently placed—printing, stationery, and current expenses are far more nearly proportional "per consumer" than per kilowatt. I will not presume to criticise the division of coal, repairs, and stores, but if two-thirds of these are chargeable per unit, a proportion of salaries and wages should be charged in that way also, for the station will not work itself, and so large a staff would not be required unless the plant were running. Mr. Hordern.

Any sum which can fairly be apportioned per k.w. should be divided per k.w. demanded by the consumer at the time of the annual maximum load, and not per k.w. of the consumer's maximum demand which, occurring at a different time, does not bear the same proportion to the total of the maximum demands as his demand at the time of maximum load bears to this maximum load. Mr. Wright's scheme does not do this, and I believe it is far less fair than the scheme of giving discounts to large consumers.

Professor R. H. SMITH (*communicated*): If the subject of this paper had been the costs of generating and distributing electric current, nothing but praise could be offered in criticism of it. It seems to give a more broad-minded, thoughtful, and searching analysis of these costs than has previously been published. In this aspect of the paper, however, two observations seem justified. On page 452 he divides the total "standbye" costs by the means of the last two annual maximum k.w. taken from the mains, and on page 448 he says that these costs "vary roughly with the annual maximum load to be provided for." This is to make, in respect of capital costs, the same error as he protests so strongly against in respect of the whole costs. The capital costs and the total of his "preparation" costs—which latter, although including many items which are not "capital" are still nearly proportionate to the capital costs—increase really roughly by the straight line law $I + w W$, where I is an initial constant, w a constant factor, and W the above maximum kilowatt. Even after many years working I may still be quite as large as w W, and for a considerable period it is by far the largest portion of the whole. If it were admitted that w W is properly distributed among the consumers in proportion to their individual maximum k.w. demand, it would still remain questionable whether I should also be charged for in the same manner. Prof. Smith.

On page 449 the author's "production" costs are defined as the increment due to making a *given* plant supply an extra unit. This definition, whether defensible or not, is an expedient which reduces as far as possible the proportion of "production" costs to the whole. It seems a daring expedient, and it should be made clear that these costs so defined are not even approximately the whole of the working costs. Although on the same page the author states that he considers alone "the steady extension stage when additional plant and mains" are being annually put down, clearly the "extra unit" defining the "production costs" does not require any such extension. But in this stage increasing demand involves such extension and along with it inevitable increase of working costs. His "production" cost is that part only of the "working cost" which varies along with the load-factor.

Prof. Smith. A careful and correct analysis of costs of generation and distribution is the most essential stimulus, and the only safe guide, to economy of installation and production. In this analysis it is of prime importance to separate truly capital from working costs, the lesson derivable from the recognition of the great relative magnitude of the capital costs being almost at the basis of sound organisation. But to think that this analysis of central station costs furnishes a scale for charging customers which is just and politic, seems to me a seriously illogical inference.

In regard to method of charging, the novel merit of the paper appears to lie in the introduction of the "diversity factor." This is defined at the foot of page 455 in very involved and obscure phraseology. To make it clearer the author's sentence may be put in the form of an equation, thus:—

$$\text{Annual Rate of Charge per maximum individual kilowatt} = \frac{\text{Total Annual Standbye Cost}}{\text{Annual max. k.w. off mains}} \div \frac{\Sigma\ \text{Max. individual k.w. in max. month}}{\text{Max. k.w. off mains in max. month.}}$$

This is the quotient of two ratios. The first is the old rate of charge before this was modified by the application of a "diversity factor." The second is the "diversity factor." Mr. Wright says that in lighting work this factor goes up to $1\frac{1}{2}$, and in motor work may go much higher. A few calculations show that this factor might possibly vary enormously without any change in either the height of the peak or in the load-factor; but how much it does actually vary can only be demonstrated by specially compiled central station statistics where the Wright system is in use. But the introduction of this factor makes the comprehension of the rate of charge needlessly difficult, the idea so expressed being a very complex one. A glance at the above equation shows that the divisors in the two ratios are really identical, and that they therefore cancel out from the result; which is simply

$$\text{Annual Rate of Charge} = \frac{\text{Total Annual Standbye Cost.}}{\Sigma\ \text{Max. individual k.w. in max. month.}}$$

This simplified form makes it at once apparent that this rate of charge is fair *as among the consumers* if it only be admitted that these standbye costs are to be distributed at all with reference to maximum individual watts. It simply means distributing them in proportion to the maximum watts taken individually. But at the same time it becomes equally clear that the "diversity factor" is a correct measure of the injustice practised *by the supply company upon the body of the consumers* when the Wright scale is imposed, as has been the usual endeavour, without the application of this factor. Its introduction is a confession of the badness of the unmodified scale. If the factor be $1\frac{1}{2}$ as stated by Mr. Wright, it means that without its application the Wright scale would impose 50 per cent. too heavy a charge on account of capital costs.

The scale is recommended as "fair" sometimes on account of capital outlay and sometimes as a necessary result of low load-factor; and these two reasons seems to be considered as fundamentally one and the same reason. But capital outlay and low load-factor are entirely distinct things, having no necessary relation. With load-factor unity there still remain inevitable heavy initial costs. With unit load-factor,

the author's "production" costs would become zero because his "preparation" costs would cover the whole; not because the factor leaves no room for *increase* of output with a given plant, seeing that these preparation costs can be calculated as easily from a decrease as from an increase of output. In this extreme case, and in others approaching this case, the sum of his two costs would be greater than the whole actual cost: and although no near approach to such condition is possible, still this consideration proves that his analysis is rationally faulty. In fact his production costs per extra unit are independent of the load-factor, and his preparation costs are equally so. Yet the existence of low load-factor is put forward as the fundamental necessity or excuse for applying the scale, while the scale itself is adjusted in accordance with the relation between production and preparation costs. Prof. Smith.

The question of "fairness" is the one that is usually argued. It ought to be understood that there is really involved no question of fairness as between the supply company and their customers. The consumers must, in one or other way, pay the whole costs, both capital and working, besides a reasonable profit, unless the shareholders go without profit. It will always be "fair" for the company to make as much profit as they can, and always "fair" for the consumers to buy electricity as cheaply as they can. The only real question of fairness involved in this scale of charges arises as between the consumers among themselves. Yet the consumers never initiate any controversy on this subject viewed in this way. A consumer complains of the unfairness of the company, but not of being treated differently from his neighbour.

The definition of the diversity-factor referred to above is a sample of the confused and obscure language employed by the advocates of the scale. On page 447 we find the "cost of individually supplying the great majority of consumers." The logical meaning of this phrase could only be understood on the other side of the Irish Channel or the other side of the looking-glass. Again, on page 457, the author says that night-users *only* render standbye costs necessary, and that none of these should fall upon day-users, forgetting that the plant could not be used in the daytime without standbye expenditure, which is necessitated by its very existence. On page 447 he asserts that a consumer with a 6 per cent. load-factor costs "always" five times as much as one with a 30 per cent. load-factor. This seems the climax of inaccurate thinking, and must have been written before the diversity-factor was invented. If he puts in his peak at the right time, the 6 per cent. consumer may cost the company absolutely nothing *extra* in standbye expenditure.

It all depends on how the consumers group themselves in timing their private peaks. If the diversity-factor were so great as to bring the load-factor near unity, then it would not matter anything to anybody whether the Wright or a flat scale were charged. But just in that proportion in which the actual state of affairs recedes from this happy condition, you prove that the central station peak is *not* the result of individual idiosyncrasies, but is the result of the population being compelled as a body to obey certain physical laws of weather and season,

Prof. Smith. laws of common industrial and social custom, etc., etc., from which there is no possibility of escape. Causes over which the individual has no control whatever being the bottom reason for low central-station load-factor, why impose a scale of charges intended to punish the consumer for naughtily obeying these laws and to encourage him—necessarily in vain—to be good according to the desire of the central-station engineer in disobedience to the laws of the universe?

Again, it is not the consumers' fault that the load curve is not levelled down by the use of storage batteries. That is distinctly the fault of the engineers and of the makers of secondary cells. It is not safe practice to base your method of account-keeping upon the backwardness of a particular department of science and industry. Moreover, a recent excellent paper on the use of storage batteries showed that in certain circumstances purchasers by the Wright scale could profitably set up batteries in their private premises. If this be so in the present unsatisfactory stage of development of the accumulator industry, it seems unsound to conclude that their use in central stations may not probably be greatly extended in the future.

Low load-factor is not special to the business of electric supply. Omnibuses and restaurants, for example, are used more at certain hours than at others, and their load-factors are low. But the standbye costs of the restaurant are not put in as a separate item on the bill presented by the waiter; and the 'bus conductor does not ask payment for two tickets, one in proportion to the distance you ride and the other in proportion to the largest number of 'busses you have ever ridden in during one afternoon in that month of the year in which 'busses are most crowded with passengers. Heavy initial outlay is also not special to this business. Coal and metal mines, gasworks, railways, cotton factories, farming, forestry, in fact, almost every form of industry, demand very large proportionate initial outlay before profits begin to be reaped. This system of charging has never been attempted in any of these industries, and would not be tolerated if it were tried.

It is evidently an illusory idea that this scale can have influence in training consumers to cultivate a good individual load-curve. If it did so, the advantage might be questionable, because in that case probably most of the individual load-curves would be very much alike, with the result that all the peaks would be superadded instead of being to some extent distributed. It remains to ask whether the scale is politic. Does it frighten away consumers with very bad load-factors and attract those with good load-factors? Mr. Wright attributes the improvement of central-station load-factor at Brighton to the operation of the scale. But does not load-factor always improve as a community develops the habit of using electricity? May not the rise of load-factor be due to a combination of many causes? Mr. Wright, page 472, says that a flat scale must encourage consumers with low load-factors. If one of these used his current for an average of $\frac{3}{4}$ hour per day, it would be a good thing to encourage him to use it 1 hour instead of $\frac{3}{4}$ hour per day. Does charging him very high for this extra $\frac{1}{4}$ hour's supply encourage him to take it? In any case, I am sure that it is illogical to assume as a necessary result of slightly flattening individual curves, any

considerable flattening of the general curve got by superimposing these. It is illogical to assume that the cost of each individual supply follows the same law as has been ascertained to be true for the common generation at the central station. It is illogical to assume as rational a scale of charge for the individual supplies off the mains simply because it imitates the law of central-station costs. Prof. Smith.

It is complained that the scale is unpopular among consumers because it is not easily understood. Is not the language in which it is described to consumers justly responsible for this difficulty? The straightforward, plain, and easily understood statement of the scale is a definite price per quarter per watt of maximum consumption plus a charge for the quantity consumed at another price per watt-hour. The usual description of "7d. per unit for the first hour and 2d. after the first hour" is not only misleading and certain to cause irritation when its misleading character is found out; it is also, as it stands and without a lot of perfectly arbitrary explanation, absolutely incorrect. The words do not grammatically bear the interpretation forced upon them: they do not mean what they are meant to mean. In the course of the supplementary explanation, it is natural to be asked, Why 1 hour per day? Why 365 hours per year? No rational relation between the one hour per day and the physical facts of the case can be suggested, because it does not exist. If the description given to a prospective consumer were that he would be charged per quarter for 91 hours' consumption at the maximum watt rate which he has used only once for a single half-hour during the quarter, and this at the high rate of 7d., and that the remainder of his consumption would be charged at 2d., this would be correct and would be easily and at once understood, with, however, the probable result that the person to whom the explanation was given would no longer be a prospective consumer. A common consumer's idea is that if he uses one lamp during the first hour of each day's lighting and any number of lamps after the first hour, he will be charged one lamp-hour per day at 7d. and the rest at 2d.; and the official wording of the charge absolutely justifies him, from the grammatical point of view, in thinking so. The unpopularity of the scale is deserved by the fact that what appears to the consumer to be its harsh feature is carefully concealed in a form of words which is not only thoroughly misleading, but is also wholly unintelligible in the sense intended without extra arbitrary and illogical explanation. This deserved unpopularity is surely a complete answer to the question whether the scale is politic apart from the question of fairness.

The application of the principle of the scale has already passed through three stages; it has reached the fourth; and the present development of electrical industry suggests a fifth. The first was the Hopkinson scale of an annual charge per lamp, or a lamp's equivalent, plus a price per unit of quantity. The second was the Wright plan of a charge per watt of annual maximum *actual* consumption in place of the watt *capacity* for consumption. The third was the basing the charge upon the *quarterly*, instead of the *annual*, actual maximum rate of consumption. The fourth has been the application of the "diversity factor" to modify the harshness of the previous scales. It cannot be

Prof. Smith. denied that each of these changes has been in the direction of flattening the scale. Mr. Wright himself says that the introduction of a large motor supply increases the diversity factor much beyond the figure it reaches with lighting alone. It appears likely that when once supply companies have got well into the thick of what is to be the bulk of their future business, namely, the driving of motors in tramcars and in workshops and in private houses for ventilation and general domestic work, they will have already forgotten that they were ever tempted to charge on any but a flat scale, with the possible exception of a more or less heavy initial charge for connection to the main.

Dr. Drysdale. Dr. C. V. Drysdale (*communicated*): Although Mr. Wright's paper more particularly concerns the power-station engineer, there is one point which he has not dealt with in his paper, and which I would venture to call attention to. The one thing which stands out through Mr. Wright's paper, and which of course must be thoroughly admitted, is that each consumer should be called on to pay his real share of the cost of production and distribution of his supply, and that where the consumer requires a supply which from its irregularity involves a large margin of power being available above his average demand, he should be asked to contribute to the expense of maintaining such a margin of power.

Mr. Wright's system of tariffs appears at first sight to meet with all possible cases except one, and that is the consumer of power on an alternate-current circuit. At the discussion on Mr. Holden's meter brought before the Institution last session, I ventured to point out that this case was one which differed somewhat from others, in that where motors of low power-factor were used, the consumer might be taking only a small amount of real power although his consumption of current might be fairly heavy, and it has been stated that the production and distribution of the wattless current probably costs about one-fourth of the true energy current supply. Although the use of power on alternate-current circuits is not as yet a very large factor in electrical distribution, yet there can be little doubt that in the future its magnitude will considerably increase, and it would be well if Mr. Wright would take this point into consideration as well. Of course, if a quantity meter is used instead of an energy meter, the consumer is debited with the total apparent power consumed, which is unfair to him, while if, on the other hand, an accurate energy meter is employed, he pays nothing for his wattless supply.

One solution of the difficulty would appear to lie in using an energy meter together with the ordinary demand indicator registering a maximum *current* supply; but a better one, in the writer's opinion, would be to use an energy meter in which, instead of removing the inductance of the shunt as far as possible, a certain amount is introduced, which inductance, although it affects but little the readings of the meter at high power-factors, makes it read too high on lagging loads. If the inductance of this shunt is properly proportioned, its readings will give a fairly close approximation to the cost of supply over ordinary ranges, and it makes the meter more easy to construct, as the driving power may be considerably increased for a certain con-

sumption of shunt current. I think this is a point which deserves some consideration, as recently we have been promised both by Mr. Heyland and Mr. Steinmetz alternate-current motors having practically a unit power-factor, and it ought to be made to the consumers' advantage to employ motors of as high as possible power-factor instead of merely considering the efficiency. I think also that meter makers may be glad to be permitted to make their meters with somewhat inductive shunts instead of having to cut the induction down to the minimum possible. Dr. Drysdale.

Mr. G. MARINIER (*communicated*): I have been greatly interested by Mr. Wright's paper on a subject of such vital importance to the furtherance of electrical undertakings, and to the more universal adoption of electric energy as a means of obtaining heat, light, and power by the general public. I therefore hope that the present discussion will call forward some practical suggestion that will lead to the satisfactory solution of the present difficulty. Mr. Marinier.

Might I, however, be allowed to make a suggestion, which, although it may not satisfy all the necessary conditions, may perhaps lead to some more satisfactory solution of the problem ?

Why not control the rate of the consumers' meters automatically from the generating station by supplying each meter with an extra magnetising coil (or other suitable arrangement depending on the type of meter used) and exciting these coils by means of pilot wires from the station at a potential difference proportional to the actual load; which could be effected by means of a small motor generator, or other suitably designed apparatus connected to the generating station switchboard ?

It could be so arranged that at some predetermined maximum load the meters would read direct in Board of Trade units, and at all other loads below that maximum the meters would not read direct in B.T. units, but in B.T. units multiplied by a decimal variable representing the facility with which the generating station supplied that particular current. The meters could further be supplied with an index reading on a scale graduated in pence per unit, enabling the consumer to see the rate at which he is paying for his energy at any time of the day.

The consumer could then be charged at a constant rate determined from such data as suggested by Mr. Wright, which rate could further be modified in favour of the poorer and more profitable consumer.

Mr. E. G. CRUISE (*communicated*): It would seem that the basis of Mr. Wright's important paper and of his original and exhaustive arguments depends almost entirely on the allocation of costs under the headings "Preparation" and "Production" on page 463. It is difficult to see that the allocation referred to can be looked upon as a rigid law by which to determine the proportion of costs in all other supply stations areas. For instance, in a 30 to 40 per cent. load-factor power scheme the allocation to "Preparation" for coal, oil, wages, etc., ought to be much smaller. Experience has doubtless shown Mr. Wright that this apportionment of the costs is the most expedient one for Brighton, but I would submit some considerations relative to a few points arising out of the paper. Mr. Cruise.

Mr. Cruise. The allocations on page 463 seem in many cases really arbitrary, and when almost the entire burden of the "Preparation" costs is thrust on the short-hour consumers, there results an argumentative loss in supplying these consumers below a certain figure. A tariff resulting from a suitable allocation can be made to encourage short-hour or long-hour consumers alternately, but the enforced application of a tariff based on page 463 cannot effectively encourage both at one and the same time.

Of the mathematical equity of the Brighton tariff there can be no doubt. The question is whether, when you have to lay down a scheme in a town where lighting alone can be relied on, such a tariff is the one best adapted to the interests of the undertakers. I cannot see that it always will be so. The primary object of an Electric Light Supply Company, or of a Local Authority undertaking such supply, should be to attract the maximum of profitable business from the most abundant class.

Lighting consumers will always be short-hour consumers in the natural order of things. Artificial light consumers burning their lamps in residential districts will never exceed three to four hours average per day, or 13 to 16 per cent. load-factor, but the majority of lighting consumers come far below such a figure. Mr. Wright has, indeed, conclusively shown in his paper that at Brighton, after nine years' working, the greatest number of consumers of a class is represented by the two-hour class, and the greatest consumption of electricity by the one to four hour class. Mr. Wright will correct me if I am inaccurate in saying that practically all this consumption represents lighting consumers. Further it is shown that at Brighton, 524 consumers (18 per cent. of the total number) did not use their lights for one hour per day. This can possibly be attributed as much to the high price ruling for short-hour consumers as to the lamps not being needed longer. Taking the population of Brighton as 115,000, the total number of consumers of electrical energy represents only some 2·5 per cent. of the population, so that presumably there must yet be a very vast number of short-hour consumers available, but who will never come on to the supply with the present tariff because gas or other illuminant is cheaper. And yet if the so-called "Preparation" costs were more equally distributed, a good profit might apparently be made from this abundant class, even if the rates for the comparatively longer hour consumers were in consequence somewhat higher. This is really the whole consideration which I present. The theoretical equity of the demand system and tariff as deduced by Mr. Wright from page 463 is unassailable, but it is rather on a power-supply basis.

Is such a tariff the one which will secure the best commercial results if short-hour consumers are the most numerous? There are an immense number of towns in England and throughout the world, where the latter conditions prevail, and will always prevail. For such towns one might choose a different tariff, and a tariff calculated to encourage this class by the lowest rates possible instead of the highest rates conceivable. Moreover it must be remembered that the increase in profit made on consumers ranging within the one to four hour class is not so very great as to warrant a discouragement of the one to two

hour class, in exchange for an encouragement of the two to four hour class, if and when the one to two hour class is the very much more numerous of the two. The principle of attracting the abundant class is not, even in the case of electric light supply, a violation of commercial axioms. A dealer prefers to trade in a cheap article in universal demand with small profit on each sale, rather than trade in an article with far greater profit only patronised by a small minority. By keeping the price to the short-hour consumers in a lighting scheme, say the one to two hour class, at the figure arrived at by maintaining the conception of costs set out by Mr. Wright on page 463, one would appear to be voluntarily excluding from custom a class which in certain towns abounds far more than the longer hour class. Mr. Cruise.

The question remains, could not the greatly increased business brought to the supply station by a more equal division of costs bring also in its train a profit which would more than make up for any transgression of the hyperbolic law of the ideally equitable system. The moment that power or really long-hour consumption becomes a really predominating factor to be dealt with, the arguments set forth by Mr. Wright in his paper must be upheld in their entirety, but in a purely lighting station in residential towns it might best pay to consider first low load-factor consumers. In a combined scheme the selection of the tariff must be adjusted in the interests of the more important and potentially profit yielding classes, and becomes necessarily more complicated.

It would certainly appear that it will be almost impossible to formulate a universally expedient tariff.

In conclusion I would like to thank Mr. Wright for his very valuable paper.

Mr. ARTHUR WRIGHT, in reply (*communicated March* 13, 1902): Mr. Wright. It is evident, from the interesting and valuable discussion which my paper has called forth, that the majority of my critics consider the question of the profitable supply of electricity quite secondary to the necessity of having a tariff which will be either very popular to the general body of consumers, or consistent with the station engineers having an easy time; in fact, the majority of the speakers have argued as if the title of my paper had been "Some Principles Underlying the Popular Sale of Electricity."

Probably owing to my having attempted to crowd too much matter into one paper, many speakers either had not sufficient time to read it, or patience to go over some of the difficult parts more than once, with the result that a number of the old stock arguments against equitable tariffs have been disinterred and warmed up again for the purpose of showing what has been recognised for some considerable time, viz., that the general public have a deeply rooted conviction that electricity can and ought to be supplied under similar conditions to gas.

Many of the most essential points in the paper have been completely ignored in the eagerness of many to attack the Hopkinson theory from the point of unpopularity, *e.g.*, no one has challenged my statement that a lower average price can be charged on the Hopkinson basis to produce a given total profit than on the flat-rate system, or that a larger

Mr. Wright. amount of profitable business can be done with an equitable scale of charges than with a happy-go-lucky flat-rate system of making the good consumers pay the losses made on the bad. Again, I had hoped that some one would have discussed my suggestion of using very slowly recording demand indicators with the object of allowing for the large diversity factor among intermittent users of electricity; and I regret that the discussion has not advanced the problem of determining the correct method for properly apportioning the profits among the various classes of consumers.

The most unfortunate omission in the discussion, however, has been in reference to the important question of the advisability of making the initial price per unit 8d., or retaining it at this figure; that no discussion occurred on this point is very disappointing in view of the Board of Trade's action of last year in suggesting the maximum allowable price should be reduced to 7d. or 6d. in certain Orders. I do trust something may yet be done to demonstrate to the London County Council how unwise they have been in attempting to make the maximum price, in Bermondsey, for instance, anything less than 8d. This tendency is so much against the real interests of the ratepayers as a body, that I feel excused in emphasising once more the easily proved dictum that the higher the initial price is made, on the Maximum Demand System of charging, the lower the average rate can be made at which the majority of the ratepayers obtain their electricity.

While I can readily understand the temptation to which many Town Councillors are constantly subjected to in the way of having to please their early-closing constituents by giving them an option of paying a low flat-rate and one probably less than the cost of supplying them, I cannot see how it can be to the interest either of a company or of a central station engineer to advocate the same commercially unsound practice. It seems to me that the very fact of any one doubting the expediency of refusing to sell except at a profit should be a fatal bar to his undertaking the responsible post of Manager to a Trading concern.

In commenting on the supposed unintelligibility of the system of charging that I have always advocated, most speakers have lost sight of the fact that any departure from the simple Hopkinson tariff is entirely due to the unfortunate privilege Parliament has given every electricity user in this country of being charged, if he chooses, solely on the basis of the quantity of electricity consumed, and of making the *minimum consumption per quarter independent of the actual demand.* If it were not for these two Parliamentary mistakes, which have led the people to believe electricity is a commodity similar to gas, no more complicated charge would need to be made than the modern telephone tariff. While granting that a charge of so much per unit is the acme of simplicity in electricity tariffs, I contend there will never be found any difficulty in getting consumers to understand the following form of equitable tariff: A monthly charge of 8d. for the first unit consumed by each 8-c.p. lamp used simultaneously, and 1d. per unit for any consumption in excess of this, during that month.

The frequent use of very imperfect analogies to electricity, by Messrs. Patchell, Mordey, and others, has been another characteristic

of the discussion. Some speakers have thought that because a sliding scale has not been considered necessary for railways, omnibuses, restaurants, and coal supply, there should be no necessity for having one in the case of electricity supply, forgetting that every one now admits the soundness of having different rates of charge per unit for tramways, public lighting, motive power and private and basement lighting. After devoting some considerable thought to the subject of analogies, I am still very doubtful as to there being any other business trading under conditions at all similar to those under which electricity has now to be supplied. The three conditions that in my mind differentiate it from any other trade are— Mr. Wright.

(1) The supplier having to produce electricity only as it is wanted, as it cannot be commercially stored, consequently his plant and mains must be governed by the maximum demand ever made.

(2) That consumers will not wait for it, and cannot be prevented from taking it whenever they like.

(3) The extreme smallness of the general diversity factor of its use.

Dealing now with the speakers in order, I must remind Mr. Patchell that none of us, either in the provinces or in London, have a monopoly in the sense that we can impose any terms on the people, as we all have to meet the competition of other forms of artificial light and power, and that supplying electricity under cost price in order to fight competition cannot be justified on commercial grounds under any circumstances, whether by a company or municipality, when trading in only one commodity. Notwithstanding the very good load-factor the Charing Cross Company has still managed to maintain for its capital, it surely ought to be a matter of some anxiety to Mr. Patchell to see that his load-factor, which, according to *Lightning's* table, was 21 in 1895, has diminished to 18·7 in 1900, in spite of the output from his stations having largely increased, which, I notice, many of the speakers consider is generally the chief reason of a load-factor's improvement. The valuable annual load-curve Mr. Patchell has had prepared is useful, in conjunction with his annual accounts, for determining at what an extremely low rate the late users of electricity in his older districts could have hoped to obtain it, had their interests not been sacrificed by his Company for the benefit of the early-closing office customers in the City. In a few years' time, when his Company's City load has developed, I trust Mr. Patchell will present to the Institution the annual load-curve on his large combined undertaking, and will then express his opinion as to the relative profitableness of two districts having such widely varying load-factors as those of the Strand and the City of London. His Company, in venturing into the City business with a low flat-rate, is certainly engaged in a very severe test of the soundness of the flat-rate theory, and no one will be more eager to discuss the subject again with Mr. Patchell than myself, after a few more years' development.

I think Mr. Mordey's case of the East End wrangler who refuses to have electricity at 2½d. per unit on the ground that he did not understand a monthly charge of 7d. per lamp and 1d. per unit, is the most

Mr. Wright. delightful example of obtuseness caused by over-study it has been my lot to hear of.

I feel certain that when Mr. Mordey can devote as much time to the reading of my paper as he has to the writing of his objections to my theories, and to the analysis of mixed-up statistics, he will not continue under the impression that the subject is beyond him. Moreover, he will find, should he get an opportunity of carrying on the business of electricity supply, that the general smallness of the consumers' annual bills is the real governing factor in determining the rapid extension of the business.

Mr. Mordey's case of the church supply is useful in showing how an incomplete examination of the subject will sometimes lead us to altogether incorrect conclusions. There is no doubt that he is correct in assuming that on Sundays during the hours of divine service the demand for light in private houses is lessened, but I would point out that the amount of plant required at central stations is not determined by the maximum load to be met with on Sunday, but generally by the demand for current during the few week-days before Christmas, at which time churches are in the habit of requiring light for services without diminishing perceptibly the load required by the rest of the town. If churches never had week-day evening services, they would, in my opinion, be entitled to a low rate of charge, but my experience at Brighton has shown that the majority have, some time during the winter half-year, as large a load on week-days as on Sundays, and I, moreover, advocate charging a very low rate to those few churches which have no load during the winter week-days.

As to the doubling of the Brighton load-factor being due to any cause other than the great encouragement given to the long-hour consumer, this is surely controverted by the fact that no other station with an equal lighting output, and charging for electricity on a flat rate, has in any way approached the Brighton result in this respect.

I do not understand the curious passage in Mr. Mordey's criticism commencing with "the object of the system being to get at an average rate," and I should have thought that even Mr. Mordey, without having to read my paper, would have learnt that the only object of my system is to make the use of electricity as general as possible, consistent with every consumer being a source of profit. Surely all Mr. Mordey's assertions to the effect that differential tariffs and demand indicators must keep down the use of electricity, are completely answered by the very extensive use of electricity in Brighton.

As to the non-productiveness of demand indicators, I consider an instrument which tends to increase the profit-earning capacity of plant as very far from being of the non-productive class.

In answer to Mr. Mordey's contention that the cost of demand indicators must prevent the poorer classes from getting electricity, I think I have proved that at Brighton and Stepney it is only by such a system that these classes are enabled to afford the use of electricity at all.

With regard to the losses of the demand indicator having to be added to those in the meter, Mr. Mordey apparently has not read Mr.

Dick's Glasgow paper on Meters, from which he would have learnt that the two measurements can be taken from one and the same energy-absorbing circuit. Mr. Wright.

I am sorry Mr. Mordey should have gone to such trouble in trying to draw conclusions from *Lightning's* tables. The results would have been interesting, perhaps, from a statistical point of view *had they been accurate*, but as he has evidently included a great number of towns having a flat rate with discounts, among those having the demand system, his conclusions can have no possible value, and are meaningless. I would strongly recommend him, if he is really in search of information, to determine whether stations using a flat rate have improved their load-factors during the last three or four years as rapidly as stations using a rigid maximum demand system. I trust he will leave out altogether those stations handicapped with the absurd combination of a demand system and an optional flat rate, as nothing can be learnt from these figures.

I am sorry Mr. Dick considers the suggestion of using storage batteries for the supply of that portion of a peak lasting only half an hour, either very new or unsound. In the first place, this has been considered a very sound method in America in dealing with the sharp peak so frequently met with in early-closing, fogless towns ; and in the second place I am convinced that the reduction of capital effected by the use of storage batteries in such towns certainly entitles the few half-hour customers to the substantial reduction in the preparation charges given on the Hopkinson system by my suggestion.

Mr. Boot is one of those gentlemen who obviously consider the convenience and comfort of central station engineers to be of more importance than the profitable extension of electricity supply. When he has time to read my paper I think he will find the modified Kapp and demand system thoroughly explained, and his daylight difficulty removed ; also that the figures given for the Brighton Preparation Coal Costs were not obtained by any arbitrary division as he suggests, but by an automatic graphical process admitting of no doubt as to the results given.

With regard to Mr. Aron's suggestion that the small five-light consumers would be properly charged on a prepayment time meter, I think one great difficulty to the carrying out of this suggestion would be that of preventing the consumers increasing the candle-power of their lamps without notification to the supply authority. From my experience I have no doubt that Mr. Aron is wrong in assuming that having once ascertained the demand of a consumer, such demand can be taken to be fixed. I think it is the universal experience that consumers' demands constantly vary, chiefly in the upward direction.

I am sorry Mr. Aron does not agree with my contention that the Kapp system of charging must necessarily maintain the higher price for a greater number of hours per day than the demand indicator system. I presume he does not contest the obvious fact that the Kapp system discourages the use of light during the usual lighting hours, whereas the demand indicator system must encourage it. I repeat that if a consumer ever requires the supply authority to provide plant for his

Mr. Wright. individual use, everything should be done to encourage that consumer to use the said plant as many hours per annum as possible, and the Kapp policy of charging a man twice as much for using plant for two hours in the evening as for one hour is commercially unsound.

It is evident that Mr. Aron has not grasped the object of the new sluggish demand indicators, as otherwise he would not have suggested that a theatre proprietor using the light an extra minute would thereby materially raise his average price.

If Mr. Andrews agrees with Dr. Hopkinson that the cost of supplying a unit in one hour is very nearly double the cost of supplying a unit in two hours, I cannot understand why he objects to discriminating between the one- and the two-hour users. If it be commercially correct to differentiate between two- and six-hour users, it must be still more necessary to differentiate between half-hour and two-hour users. The comparison of the results of Brighton and Hastings must surely convince Mr. Andrews that the irregular incidence of the quarterly accounts in the former town can have had no real effect in retarding the business or a less improving effect on the load-factor, as both the general use of electricity and improvement of load-factor are startlingly greater in Brighton than they are at Hastings, in which latter town the load-factor seems actually to have *diminished* 8 *per cent.* during the *last five years.* It seems curious that Mr. Andrews, after his careful study of the subject, has not yet realised that the very fact of his giving the consumers the option of paying 6d. per unit enables those who use very little electricity in the summer to get off paying their proper share of the preparation costs; in fact, his flat-rate option does away with all the benefit Dr. Hopkinson's system was intended to give. As to Mr. Andrews' claim that his quarterly charges bear some near proportion to the quarterly consumption of current, I would point out that this can only mean either that the flat rate is more correct than the Hopkinson tariff, or that only consumers with approximately equal quarterly consumption are referred to, as it certainly cannot be true when applied to all classes of consumers with the varying load-factors met with in practice.

Mr. Madgen seems to be one of the few speakers who realise that it is more important for central station men to aim at always trading at a profit, than to increase the capital cost of the undertaking with the chief object of being popular among the consumers.

Mr. Minshall is another gentleman whose speech would seem to imply that he thinks that the comfort of the central station engineer is of prominent importance, whereas, knowing him as I do, I feel sure that he will be the first to agree with me that if engineers do not put the interests of their shareholders before their own comforts, there is a great danger of engineers being told in the future to only concern themselves about engines and to leave the commercial management of the business to business men. I think Mr. Minshall's practice of increasing the number of hours in the winter quarters, during which the high price is maintained, is a very much better way of making the incidence of the charge proportional to the consumption of current than that advocated by Mr. Andrews, and I commend his ingenious

idea of making out the bill, on the basis of the average price, to all central station managers. I would suggest carrying the principle still further by making out the bill for so many units for so much £ s. d., leaving out all the unnecessary details of price per unit. Mr. Wright.

I notice Mr. Minshall, in one of his remarks, implies that the fact of his having public lighting and traction supply has affected his private lighting load-factor. Surely the load-factors of these three services are absolutely independent of one another.

I think Mr. Beeton has done all central station men a real service in insisting on the importance of engineers becoming conversant with ordinary commercial principles and in proving how little the average man cares about the principles on which his daily purchases are charged, provided the total bill is satisfactory.

I think if Mr. Still will read my paper he will find the cases he mentions, of the maximum demands of the early-closing shops and private houses not being coincidental, fully dealt with. I certainly cannot understand Mr. Still, with his long study of the question of tariffs, doubting my statement that by charging all his consumers 10d. per unit for, say, three-quarters of an hour per day he would be enabled to profitably supply the poorer districts of Chelsea at a lower price than he can at present.

Mr. Wilson is another gentleman who, not having read my paper, assumes that I take it for granted that all the demands are made simultaneously. Pages 455 to 458 of the paper are devoted to the consideration of the contrary state of things. Mr. Wilson has not correctly stated the difference between my views and those of Mr. Kapp. The essential difference between us seems to me to be that Mr. Kapp considers all lighting at the peak time should be discouraged, whereas I consider that any lighting business that can be done at a *profit* should be encouraged regardless of the hour at which it is required. I am sorry he should consider the absurdly simple formulæ on page 481 a proof that the theory I am advocating is surrounded by mystery and mathematics. I can never admit that there is any mystery about the subject, or that anything more than simple commercial arithmetic is necessary for its proper study. When I inform Mr. Wilson that three clerks at Brighton can carry out all the work connected with the application of the demand indicator system to over 3,500 consumers, he will doubtless appreciate how automatic in its working the system can be made.

Unfortunately for Mr. Wilson's coal-mine analogy, coal has proved itself capable of being stored very efficiently for millions of years, whereas, as I have said previously, electricity has to be used directly it is made. Here is another instance of the dangerous use of imperfect analogies.

It is very difficult to know how to deal with an opponent such as Mr. Hordern, who starts off by denying the very basis of the Hopkinson system. What can, for instance, be said to a critic who disputes the usually accepted statement that, given an equal consumption, the capital outlay involved in supplying a consumer with a thousand lamps used on the average one hour per day is roughly ten times as much as that

Mr. Wright. required to supply a consumer with one hundred lamps ten hours per day. I am afraid I cannot again attempt to prove to Mr. Hordern the truth of such propositions, or even to convince him that a large early-closing business paying 4d. per unit produces very much less total profit to the supply authority than the small five-light private bouse user.

Mr. Hordern, like Mr. Boot, imagines my analysis of the Brighton revenue charges have been carried out arbitrarily, instead of by automatic differentiation.

I must express my indebtednesss to Professor Smith for his very careful and elaborate criticism of my paper. With regard to his doubt as to the correctness of dividing the preliminary costs equally among the kilowatts demanded by the consumers, as these costs were undoubtedly incurred for the benefit of all the consumers, the course I have taken seems a perfectly fair one.

Professor Smith unnecessarily complicates the analysis of electricity costs by introducing the term "Working Costs"; these must be necessarily a combination of both preparation and production costs, and the whole object of the differentiation of these two, is to avoid this unnecessary but very usual mixing up of dissimilar charges to the revenue account.

I disagree with his insistance on the necessity for separating capital from working costs. I think most of the hazy ideas on the subject of electricity tariffs are due to the use of the term "Working Costs," which really form only part of the total costs.

Far from the diversity factor being a new feature in the study of tariffs, as Professor Smith seems to think, it is probably one of the first things any central station engineer discovers who has measured the actual demands of his consumers. The chief objection I have to his simpler formula for determining the preparation costs per kilowatt demanded by the consumer, is that it gets rid of one of the most useful factors used in the comparison of various stations, viz, the diversity factor, and its omission obviously invites the criticism, that has been so frequently made use of in the present discussion, to the effect that the demand indicator system assumes all demands are made simultaneously, which is far from being the case.

I cannot make out what Professor Smith means when he says that with a load-factor of unity (I presume he means really 100) production costs would become zero. Surely this is nonsense. The preparation cost per kilowatt would remain the same, and the production cost per unit would also remain the same. The only effect of the increase of the load-factor would be to make the total production costs per annum greater than with a smaller load-factor. It is equally a mystery to me why Professor Smith, realising as he does that the preparation cost per kilowatt and production costs per unit are independent of the load-factor, should say my reasoning is faulty on the ground that the sum of the preparation and production costs would be greater than the whole in the case of 100 per cent. load-factor. Where he gets this *reductio ad absurdum* I am at a loss to understand. Is he not mixing up total production costs per anum with production cost per unit? As to his hypercriticism of my statement that a 6 per cent. load-factor consumer

must cost for preparation five times as much as one on equal consumption with a 30 per cent. load-factor, surely the context ought to have shown him what was meant and prevented him creating the *rara avis* of a 6 per cent. load-factor consumer who *never* uses his demand during the ordinary lighting hours. Mr. Wright.

Professor Smith, in common with several other speakers, talks of my punishing a man who has only very natural proclivities. If asking a man to pay a fair profit on the cost of supplying a commodity is a form of punishment, I plead guilty, and glory in my being in the very large company of ordinary traders.

Professor Smith also indulges in the use of very faulty analogies and takes the cases of restaurants and omnibuses, forgetting that if a restaurant or an omnibus is full, intending customers have to wait or have to go elsewhere, whereas in the supply of electricity consumers will not and do not wait, but insist on taking their supply whether it interferes with the supply given to others or not; and moreover nothing can be done to prevent these impatient customers from so doing. As to a differential scale of charges not being tolerated in the supply of other commodities than electricity, I entirely disagree with Professor Smith. Where there is a distinct advantage to both the supplier and consumer alike, equity of charging will, in the end, beat mere simplicity in any business having to face competition.

In his last paragraph but three, Professor Smith refers to the doubtful advantage of having consumers who add to the peak of a supply station. This curious, but frequently made statement, either means that an increase of business is bad, or that no peak business can be profitable, both of which propositions I deny absolutely. I moreover say it is the duty of managers of electricity supply business to extend their business as much as possible, and make all consumers as profitable as possible, but above all never to sell at less than cost price, unless compelled to do so by Act of Parliament. Professor Smith is apparently not aware that our Parliament has prevented a simple Hopkinson tariff being alone offered to the consumers of electricity in this country.

I cannot agree with Professor Smith that the modified demand indicator system I am advocating tends in any way to flatten the scale of charges. Take, for instance, offices closing at six o'clock every day. Nothing I have suggested ought to bring the price charged to such consumers under the present highest permissible rate, or bring the charge to the power day user up to the average price paid by the whole body of consumers. His reading of my reference to the motor diversity factor is incorrect. I did not say that motor load will increase the general diversity factor, but stated that the diversity factor among motors was generally higher than among lamp users.

I have always considered that the correct method of dealing with the alternating-current meter problem Dr. Drysdale mentions is to have the annual charge for preparation based on the maximum demand in amperes, and to couple it with a charge for the actual consumption in units, and hinted in my paper on the mistakes that had been made in framing the Power Bills in this connection in the ninth anomaly, on

Mr. Wright. page 446. I consider the above suggestion to be much more correct than the ingenious one suggested by Dr. Drysdale, which would prevent the meters reading direct in Board of Trade units or in any other easily checked units.

The old Norwich system of carrying out the Kapp principle which Mr. Marinier advocates, has all the disadvantages of the Kapp clock system coupled to the disadvantage of being in practice excessively costly to carry out. Mr. Oxley, in America, has suggested a neat way of carrying out the Norwich system without the use of a special wire, and Mr. Funkleman, of Paris, has shown how a very perfect demand indicator system can be worked by means of a pilot wire.

Mr. Cruise is another gentleman who imagines the analysis of the Brighton figures into preparation and production costs has been done arbitrarily, notwithstanding all the letterpress devoted to the explanation of Diagram I. of my paper.

Mr. Cruise assumes, for some reason, that the short-hour consumer has to pay more for the preparation costs than the long-hour one. I must remind him that all consumers have to pay the same rate per kilowatt for preparation costs. He suggests that the remedy for the small number of short-hour users in Brighton would be to lower the price to them, but he has apparently not learnt from my paper that such a course would be carrying out the very opposite policy to the one I recommend; in fact it would be doing what I say the flat-rate system does, viz., encourage the short-hour consumer and discourage the long-hour consumer, thereby raising the average price, lessening the amount of business done, and very much limiting the field for future extension.

Mr. Cruise's suggestion that the short-hour consumers should be encouraged on account of their number, must remind one of the very useful story of the old lady who, whilst admitting that she lost a halfpenny on each apple she sold, was under the impression that it was the quantity she sold that paid.

Like most prolonged discussions, the present one has suffered from the opposing parties looking at the problem from different points of view. If, however, anything has been said which will check the present tendency to lower the initial price below eightpence per unit, to stop the ridiculous practice of giving consumers the option of being charged on a flat rate if they do not find the maximum demand system works out to their advantage, and to get the Board of Trade to allow a minimum charge to be made of, say, three units per quarter per 8-c.p. lamp demanded, I shall feel that the object of my paper has been accomplished.

The Chairman. The CHAIRMAN: As the hour is very late, I must ask those who wish to further join in this discussion kindly to send in their remarks in writing, and they will be added to the paper. I am sure you will all agree that Mr. Wright deserves our very best thanks for having brought forward such a well-thought-out paper on such an extremely interesting and important subject. I will ask you to pass a hearty vote of thanks to him for his paper.

The vote was carried by acclamation.

The CHAIRMAN announced that the scrutineers reported the following candidates to have been duly elected :— The Chairman.

Associate Members :

Louis John Hunt. | Philip Grant Wayne.

Associate :

Henry Carter Watson.

Student :

Henry Benjamin Bennett.

The Three Hundred and Seventieth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 9th, 1902—Mr. WILLIAM E. LANGDON, President, in the Chair.

The minutes of the Ordinary General Meeting held on December 19, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

John Kempe Brydges.

From the class of Foreign Members to that of Members—

Henry Fleetwood Albright.

From the class of Associates to that of Members—

Edward O'Keeffe.
William Grigor Taylor.

From the class of Associates to that of Associate-Members—

Walter Binns.
Alec D. Chalmers.
Alexander Charles Cramb.
E. G. Fleming.
Frederick Simmons Grogan.
Arthur William Higgs.
Richard Humphries.
Frank Johnston.
L. Johnston.
Henry Ivan Lewenz.
Edgar Walford Marchant.
Thomas Mather.
Herbert Leslie Mills.
Septimus Pauls.
Walter Riggs.
Archie Corbett Seaton.
Walter A. Vignoles.
Edmund Basil Wedmore.
Sydney Woodfield.

From the class of Students to that of Associates—

William Arundell.
Arthur John Bohringer.
Edwin Olding Chadwick.
Percy Douglas Collins.
Frederick John Holmes.
Henry Joseph.
Reginald George Madge.
Charles Basil Nixon.
Charles Hallewell Steele.
Hedley Jeffreys Thomson.
Walter Talboys Wheeler.

Messrs. G. W. Green and W. J. Grey were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. E. Garcke, A. Heyland, and F. Kerntler; to the *Building Fund* from Messrs. J. K. Bedford, I. Braby, A. Burton, G. Byng, M. Byng, P. Cardew, R. A. Dawbarn, W. Duddell, H. J. Eck, S. E. Glendenning, W. Golledge, R. Hammond, H. E. Harrison, T. H. Harrison, A. Hay, H. Hirst, H. W. Kollé, A. E. Levin, A. P. M'Douall, H. W. Miller, J. Rance, J. H. Rosenthal, W. M. Rolph, A. Rutherford, J. Shaw, W. Smethurst, J. M. Smyth, A. Stroh, J. W. Swan, A. A. C. Swinton, F. W. Topping, C. Turnbull, L. Wilson, H. W. Young; and to the *Benevolent Fund* from H. Bevis, I. Braby, G. Byng, M. Byng, Major Cardew, H. J. Eck, R. T. Glazebrook, H. J. Glynn, H. Hirst, A. E. Levin, G. W. Money, Sir David Salomons, W. C. Smith, A. Stroh, E. B. Thornhill, and J. Woodside, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: Gentlemen, I have very much pleasure in wishing you all a very happy and prosperous new year. We none of us know what the year may have in trust for us, but we all hope that it will be bountiful in the advancement of electrical science and its many applications.

We were on this occasion to have had a paper by Professor Barrett, and I am afraid you may have been caused some inconvenience in consequence of our having to forego that announcement. Professor Barrett has unfortunately been suffering from a severe cold, and it was felt it would be improper on our part to urge him to venture under such circumstances to cross the Channel for the purpose of reading his paper, especially as there was just a possibility that he might not, in fact, be able to do so. It was therefore decided to bring forward the Reports on the visit to Germany. These reports, as I daresay you understand, are rendered by gentlemen who were appointed by the German Visit Committee to collect information that might be of interest to members. Mr. Patchell has been kind enough to undertake the duty of reporter on Traction, Light, and Power Distribution, of which Committee he is Chairman; Colonel Crompton, as Chairman of the Committee on Manufacturing, has undertaken the duty of reading the Report on Manufacture; and Mr. Kingsbury, the Chairman of the Committee on Telegraphs and Telephones, has undertaken the duty of reporting upon that subject. These subjects will form, as it were, a continuous paper dealt with under the three heads. They will be treated as papers, so that members present may have the opportunity of discussing any points brought forward in them. I hope they will lead to an interesting discussion. Each of those gentlemen who have been kind enough to act as reporters have expressed their desire to afford any further information in their power which might be asked upon the subjects dealt with in their reports. I will now ask Mr. Patchell to proceed with the reading of his section.

Mr. W. H. PATCHELL: Gentlemen, before I begin, may I take the opportunity, on your behalf, of heartily reciprocating the President's good wishes, and express the hope that the rest of the winter will deal more kindly with him?

REPORT OF THE COMMITTEE ON TRACTION, LIGHT, AND POWER DISTRIBUTION TO THE COUNCIL OF THE INSTITUTION OF ELECTRICAL ENGINEERS ON THE VISIT OF THE INSTITUTION TO GERMANY IN 1901.

Ownership of Works.—A close connection between the manufacturers of machinery and the supply of electrical energy in Germany is very noticeable. This intimacy between the supply and demand for machinery is very much to the advantage of both the manufacturer and the user, and in the case of municipalities there is no doubt that while maintaining their control over the work within their area, it has been the means of strengthening and consolidating German manufacturing interests.

In Berlin we find the Electricity Works owned by a Limited Company founded by and in very close touch with the Allgemeine Elektricitäts Gesellschaft. A few of the early machines are of Siemens and Halske construction, but latterly the whole of the electrical machinery and cables have been supplied by the Allgemeine Elektricitäts Gesellschaft. The company works under a concession from the Municipality which has been renewed on a very much larger scale than the original concession, which has necessitated the building of very extensive works outside the city at Moabit and Oberspree. These works, at present under construction, augment the supply, and will probably in time supersede the smaller works inside the area of supply.

At Charlottenburg, Wiesbaden, Homberg, and Bockenheim the works are owned by the Municipality and leased to the constructors, Messrs. Lahmeyer, on terms which, while securing a return to the owners on the capital invested, encourage enterprise and extension on the part of the contractors.

Prime Movers.—The first thing that strikes an English engineer on entering a German engine-room is the magnitude and frequently the elaboration of the buildings.

The engines commonly used are of the horizontal slow-speed type of from 100 to 80 revolutions a minute, though in some cases vertical engines are found. The finest examples of the latter were the four-cylinder triple-expansion sets seen in the Luisenstrasse Works in Berlin, where three each of 3,000 I.H.P. by Messrs. Sulzer are at work. It is generally considered that although the vertical engine occupies somewhat less ground space, it costs more in attendance and is higher in prime cost, which may be the reason for the Berlin Company adopting horizontal engines for their new stations where the units are each of 4,500 I.H.P. The personal element also influences the adoption of horizontal engines, as we learn that men do not give the same attention to the working parts if they have to climb ladders to get at them. Those of us who were in the Paris Exhibition last year must have been much struck with the number of men employed on the galleries of such engines as Messrs. Borsig's magnificent vertical.

The enclosed-type high-speed engine so common at home is con-

spicuous by its absence on the Continent, although some makers are now partially enclosing their vertical types.

In horizontal sets the draught caused by the dynamos has been found to draw the oil from the connecting rods and crank bearings on to the winding, and in order to overcome this the frames or trunks of horizontal engines are now much more enclosed than was usual before dynamo driving had to be considered; the greatest advance in this direction being seen in the new 1,000 I.H.P. sets at present being fixed at the Dortmund Works.

Forced lubrication as understood at home is unknown, though definite plunger feed lubricators are generally used instead of gravity sight feed drop lubrication for cylinders. The highly finished valve-gear on the slow-speed engines would appear to need considerable attention, but it is commonly found that well-finished machinery gets well looked after by the attendants, who take more pride in an engine that looks well when it is clean than in more roughly finished work that barely shows when it is clean or not. Good lubrication and hardened wearing parts for the trips of the valve-gear reduce wear and tear to a minimum, and the engineers in charge report that repairs are insignificant.

Boilers.—Water tube boilers, with the tubes expanded into a common header, are almost universal, and super-heating up to 50° C. is very common, generally by separately fired super-heaters, although in some cases nests of tubes are used in the boiler setting. In a few cases economisers are used, but they do not appear to be as general as in England. Furnaces show a very interesting departure from English practice in inclined grates of the Tenbrink type.

In spite of the "Verboten" issued against smoking two years ago, we saw a good deal from the chimneys in many towns. In Berlin the City Council control the emission of black smoke, and for that reason the Electricity Works are restricted in the use of coal which, we understand, has been up to the present purchased from Cardiff. At the Moabit Station, which is on the outskirts of the city, a class of coal very similar to our Midland slack is used, while farther out at Oberspree brown coal is used. In both these latter cases we are told no trouble from smoke was experienced.

Bucket elevators and belt conveyers for coal were seen in the A. E. G. Station and the Siemens and Halske's Overhead Railway Plant in Berlin, also in Dresden, though tip-trucks delivering coal in front of the boilers appear to be the rule. Mechanical stoking is conspicuous by its absence.

In Dresden, where brown coal is used and automatically fed on to the grates, the ashes being taken away in the basement, the boiler-room is cleaner than many engine rooms. In Essen a very interesting example of firing with waste gases from the adjoining coke ovens has been arranged for, though at present coal is being used.

Generators.—Dynamos are very large everywhere, the slow-speeds generally obtaining making even a 300-kilowatt machine impressive. Splendid examples of machines of over a thousand kilowatts were seen at Berlin, Dresden, Essen, etc. The continuous-current fly-wheel generators are of special interest. These machines are a speciality of

the E. A. G. vorm. W. Lahmeyer & Co., and are erected in many of the central stations built by them. Such machines were seen running at the central stations of Dortmund, Dusseldorf, and Homburg.

Two continuous-current machines direct driven by the same engine and connected alternatively in parallel for lighting or in series for traction may be seen in Berlin and Dusseldorf. In Homburg, one engine may be seen driving two generators of different pressure and size for traction and lighting, the traction generator acting as fly-wheel for the whole set. This interesting arrangement requires very little space, and is due to Messrs. Lahmeyer.

The bulk of the new work appears to be on the three-phase system, and the varied use of it is very interesting. Many central stations are built for three-phase current distribution, with continuous-current sub-stations. The oldest German works built on these lines were erected in Bockenheim, near Frankfort-on-Maine, in the year 1892 by the E. A. G. vorm. W. Lahmeyer & Co. These works were also visited by the members. It is specially worthy of mention that from the very beginning synchronous motors were used for equalising phase differences, and Bockenheim is therefore one of the oldest plants where synchronous motors were used for the said purpose.

The Berlin Electricity Works illustrate the adoption of the three-phase system by a Continuous-Current Company as soon as it became necessary to transmit energy on a large scale from stations at some distance from the centre of the town; with some 30,000 H.P. in continuous-current dynamos, the new stations are laid down at Oberspree and Moabit for a total of 90,000 H.P. with unhesitating confidence in the three-phase system.

At Charlottenburg, with a population of 150,000, the three-phase system has been adopted by Messrs. Lahmeyer at the beginning, but in combination with a continuous-current supply, the relative proportions of the two generating plants being about 6 : 4. This station may be taken as a good instance of a modern station of fairly large size (2,000 K.W. generating plant) supplying light and power for Traction.

In the factories visited a rough guess would place the direct- and alternating-current machines under construction as about equal in number and importance, although actually the largest machines were alternators. Under the latter class there were very few single- or two-phase machines to be seen. For new work, Inductor Alternators are practically extinct; not a single one was seen under construction in any of the shops, and although this may have been an accident, certainly their proportion to the whole number built must be small.

The number of direct-coupled machines in course of construction in the workshops of the E. A. G. vorm. W. Lahmeyer & Co. was very large. The continuous-current fly-wheel generators for the extension of the Düsseldorf and Dortmund Municipal Works and for the central station at Münster, driven by gas engines aroused especial interest, as also did the H.T. 1,600 K.W. Generators for 10,000 volts direct pressure. A number of synchronous and asynchronous motor generators up to 450 H.P. for the same high pressure were also nearing completion. A

remarkable instance of direct-coupled machines appears in the motors for pumping plants, of which quite a number, varying from 300 to 600 H.P. at 60 to 80 revolutions per minute were to be seen in the workshops of Messrs. W. Lahmeyer & Co. in the course of construction.

For the general purposes of transmission and lighting a standard periodicity of 50 is now almost universal in Germany, the variants of 40 and 60 being seldom found. Rotaries up to 800 kilowatts are run at this periodicity in the Berlin sub-stations.

Rotaries and synchronous motor generators were seen at Berlin and Frankfurt respectively under very similar circumstances, both being at work on traction loads, and on their respective merits there was little to be gleaned without a closer knowledge of details. The arrangement of a direct-coupled booster on the alternating side as seen at Augusta Strasse, Berlin, due to Herr Dobrowolski, by means of which the primary pressure can be varied, overcomes the difficulty of the fixed ratio of conversion in the rotary.

Motors.—At Frankfort the larger sizes of the single-phase motors were started in the usual way on a loose pulley. As to the smaller sizes which were used on lifts, many who saw the mechanism came away with the idea that the lift started simultaneously with the motor (see *Engineer*, July 26th), yet the reporter of the *Electrician* was informed that there was a time arrangement allowing the motor to start before the cage is lifted (see July 19th). We mention this point, although not of great importance, in case there may be further reference to it by others, and by way of caution as to what were really the facts in connection with a rather complicated piece of mechanism.

After experience with continuous-current motors at their Ackerstrasse Factory, the Allgemeine Elektricitäts Gesellschaft adopted three-phase motors for their Brunnenstrasse Factory throughout even for their cranes. The reason for this is partly to be found in their adoption of separate motors practically for every tool, the capital outlay on a large number of small motors being at that time (if not now) less, if they were three-phase than if they were continuous current. In the factory at Oberspree, which is still more modern, although all the tools are driven by three-phase motors, the cranes are again driven by continuous-current motors fed from motor generators, which also supply direct current for inverted arc lighting. Although at Oberspree there are some 3,000 H.P. of motors, yet the current is taken from the adjoining central station, although the load must be a constant one well adapted for great economy in its production, the expense of the step-down transformers must be outweighed by the low price charged for the current. Other factories also use polyphase or direct-current motors according to the prevailing conditions as motive power for their workshops. In the works of Messrs. Lahmeyer & Co. polyphase motors are used for driving groups of machines, whilst single machines are driven by continuous-current motors. The new works, situated some distance from the old works and its central station, are driven exclusively by polyphase motors.

Storage Batteries.—The use of storage batteries is much greater in

Germany than in this country, the proportion they bear to the generating plant often reaching 20 to 25 per cent. They are used not only to level the load on the generators, but in Frankfort they enable synchronous motor generators to be used for the conversion of single-phase current to 500-volt continuous current for the trams, such use having been found simple and successful, and it is stated that they completely stop the hunting of the motors.

The batteries in Frankfort are charged by an induction motor-driven booster, and in the Augusta Strasse station of the Berlin Company by a combination of rotary converters and synchronous machines.

The positive plates are generally of the Planté or formed type, while the negative are of Faure or pasted type, and maintenance contracts with the makers appear to be the rule rather than the exception.

Cables.—As regards cables for the transmission from Oberspree, over nine miles, 6,000 volts is the chosen voltage, and at this pressure the mains are laid underground. The general type of cable employed by the A.E.G. for transmission at moderately high pressures was said to be insulated with impregnated jute, lead-covered and armoured and buried in a bed of clean sand direct in the ground; for pressures from 5,000 to 10,000 volts impregnated jute, rubber and a covering of paper, lead sheathing and armouring; for higher pressures up to 20,000 volts rubber and stabilit instead of jute, experiments being shown to demonstrate the superiority of the stabilit cable at the Oberspree Cable Works. The cables from Oberspree are twisted three-core, and seven are used to feed the sub-station at Mariannenstrasse, which takes about 7,500 H.P., so that the power transmitted by each cable must be at least 1,000 H.P., and probably to allow of reserve capacity, each cable transmits about 2,000 H.P. The best practice appears to be double cables in sections with triple-pole two-way switches, so that the reserve sections may be switched in in the event of a fault occurring. Lightning arresters are freely used, but we were not able to obtain any definite information about the general practice in transmission lines.

The frequent use in Germany of an uninsulated middle wire in a low-pressure three-wire network is very interesting. It is a very important point, as if it were permitted in this country it would very considerably reduce the cost of networks, although we must admit the benefit to be derived from such a saving is not looked upon by all engineers with equal favour.

Tramways.—For tramways a pressure of 550 volts is still the rule, and the sliding bow appears to be extending faster than the trolley.

The span-wire is usual, the trolley-wire being everywhere kept as close as possible to the centre of the track. The sliding bow introduced by Messrs. Siemens, with its friction surface of aluminium crossed lengthwise for lubrication, gives a simpler overhead construction at curves and junctions and more latitude in the position of the overhead wire. The sliding of the bow gives quieter running than do trolleys, but it is very doubtful if on the whole the system be preferable to the better examples of swinging trolley equipment seen in England.

The rail-joints are often scarfed, which gives smooth running.

Lightning arresters of the Horn or Siemens type are largely used for traction service and placed above tramcars with a gap of about $\frac{1}{8}$ inch for 500-volt circuits, the width of the horns at the top being about 5 inches. Wider streets, and the fact that cars do not stop except at their recognised stopping-places, enable high speeds to be run.

Accumulator cars are much used in the centre of large towns, notably in Düsseldorf and Berlin, although in Dresden Messrs. Siemens' conduit system has been adopted through the centre of the town. This modification does not appear to be due so much to economical reasons as to meet the æsthetic views of the municipalities concerned.

High-speed Railways.—The experimental trains in hand at the works of Messrs. Siemens and Halske and the A.E.G. elicited great interest. A few particulars of Messrs. Siemens and Halske's equipment will be found in Mr. Sheardown's paper before the Dublin Local Section, Nov. 14, 1900 (this Volume, p. 611). For further particulars of the latter we would refer members to Herr O. Lasche's very important description presented in his paper read before the Electrical Section of the International Engineering Congress at Glasgow (*vide* this Journal, 1901, Vol. 31, p. 24).

The Suspended Railway.—The Langen Mono-Rail Suspended Railway from Barmen to Eberfeld marks an epoch in railway work. The line, which is rather more than eight miles in length, runs for some six miles over the bed of the winding River Wupper, carried on A-frames about 30 yards apart. The other two miles, over narrow streets and country roads, is carried on horseshoe-shaped frames, as they offer less obstruction to traffic than the sloping sides of the A-frames. The underside of the cars is about 15 feet above the street level. The track is double, providing for "up" and "down" trains of two fifty-passenger cars, which are each suspended from two bogies 26 feet apart. Each bogie has two wheels 35 inches in diameter running on the single rails with an overhung 36 H.P. motor between them, whose pinion engages with spur wheels on the axes of the 35-inch driving-wheels.

The 550-volt direct current to the two lines is supplied by separate Sulzer-Schuckert 850-k.w. generators. There are also buffer batteries in the generating station, to ensure safety. The current is picked up by contact shoes, which are pressed by spiral springs on to an ordinary round-headed iron rail conductor. The track is divided into automatic block sections, and trains can be run every three minutes at a speed of thirty miles an hour. The whole of this novel electrical equipment was designed and constructed by Messrs. Schuckert, of Nürnberg.

Conclusion.—The following figures, although incomplete, will prove interesting.

The Berlin Electricity Works, in their six generating and battery stations, have a total capacity of 84,000 k.w., and the highest load observed is 60,000 k.w.

In the year ending June, 1900, they generated 62,300,000 units, and sold about 50 millions as follows :—

For.	Units.	Prices obtained.
Private lighting	11,200,000	6d.
Street lighting	800,000	7·2d., including carbons and attendance, plus £6 per lamp for hire, etc.
Motors	17,300,000	1·92
Trams	20,200,000	1·08
Used on stations	500,000	—
Total	50,000,000	2·78

Cost of coal, Local, 11s., Small Welsh 17s., per ton.

Costs of labour are not excessive :—

Dynamo attendants and engine-drivers	4d. to 4¾d. per hour.
Switchboard attendants	4¾d. to 5¼d. " "
Stokers	4¼d. to 4¾d. " "
Cleaners, etc.	3¾d. to 4d. " "

In Dresden the prices charged by the City Light Works are—

For lighting	7·2d. per unit.
For power	4·0 " "

Cost of local coal, 11s. per ton (poor in quality).

In Dresden Power Station, which supplies the trams, the charge works out at about 1·5d. per unit, but it varies. The city charges the tramways with all the expenses of generating the current, and then takes 25 per cent. of the tramways profit.

In conclusion, the Committee would gratefully record the kind offices of their reporters : Messrs. L. Andrews, A. N. Foyster, C. C. Hawkins, D. K. and J. T. Morris, G. Ralph and J. J. Steinitz, to whom the members are indebted for the details of this report of a most interesting and instructive trip.

REPORT OF THE COMMITTEE ON MANUFACTURING TO THE COUNCIL OF THE INSTITUTION OF ELECTRICAL ENGINEERS ON THE VISIT OF THE INSTITUTION TO GERMANY IN 1901.

For convenience, the matter dealt with has been grouped under the following headings :—

1. Financial.
2. Works management.
    a. Buildings.
    b. Staff.
    c. Labour.
    d. Treatment of employés.

e. Machine tools.
f. Driving of shops.
g. Miscellaneous.

3. Design, etc.
a. Switchboards.
b. Direct-current dynamos and motors.
c. Alternators and alternating-current motors.

1. Financial.

This question possesses considerable interest, as, at the time of the Institution visit, the German electrical industry was passing through a severe financial crisis. It would appear that the German Group Banking System, while enabling firms to start with ample capital, and therefore also with well-equipped works, has the disadvantage of fostering over-extension and over-production to such a degree that a period of trade depression becomes hard to face. The early summer of this year saw the collapse of two important industrial banks, and with them of one well-known electrical firm. A strain was thrown upon the whole industry, and under the circumstances it seems doubtful whether the system is really such an unmixed blessing as some would appear to suppose.

The large and well-equipped works which are possible under this system have, of course, the advantage of reduced shop and management charges. Furthermore specialised machine tools can be economically employed and the staffs can be more highly paid, while the heads of departments may specialise to a greater extent. Whether, however, there is much gained in this direction after a certain size has been reached would appear doubtful.

The financial relations which exist between the manufacturers and the banks on the one hand, and their customers on the other, would appear to be so extremely complicated that progress is to some extent retarded, though the system undoubtedly enables experiments to be carried out on a much larger scale than would be otherwise possible.

It is a very noticeable fact that the consulting engineer occupies a much less prominent place in Germany than he does in this country, owing, it would seem, to the same cause. It might almost be said, in fact, that the entire consulting work of Germany is carried out by two engineers, one of whom, be it stated, spent the greater part of his professional life in England.

2. Works Management.

a. Buildings.—Large works follow from large undertakings. There are two distinct ways of erecting large works. Of the first of these, which consists in building one large shop, the Allgemeine Elektricitäts Gesellschaft of Berlin is a typical example, while Messrs. Schuckert's Nürnberg factory may be taken as representative of the plan of splitting up the works into several relatively smaller buildings. Each system has its advantages, and up to a certain size no doubt the ease with which material can be handled and transferred from one department and another, the accessibility of every department and the general com-

pactness, tell in favour of the first method. After a certain size, however, these advantages are less marked, and against them must be set the fact that it is almost impossible to extend one department without in some way encroaching upon another. Further, there is more chance of friction between neighbouring heads of departments where boundaries are to a large extent imaginary. It may be of interest to note that in America the Westinghouse Company lean to the large building plan, while the General Electric Company split up their works, on the second principle mentioned.

As regards the organisation of departments, again two methods are possible. First, certain articles can be manufactured throughout in one department, or, secondly, all work of a similar nature, no matter for what purpose, can be carried out in the same department. Of the first system the Union Elektricitäts Gesellschaft of Berlin would appear to be the best example, while perhaps the A.E.G. instrument factory in Akerstrasse, Berlin, and Messrs. Siemens and Halske's telegraph factory in Markgrafenstrasse might be included. The second method, however, seems to be by far the most general.

b. Staff.—One of the most noticeable features in all the works visited was the very large engineering staff employed. Out of five firms of whom inquiries were made on this point the following were the proportions of staff to employés: 1 to 20; 1 to 7; 1 to 10; 1 to 13; 1 to 20.

It was somewhat difficult to find out exactly what was meant by "staff," and it is possible that the above figures in many cases include some of the commercial department. Probably, however, after making all allowances, the average proportion would be one engineer to every ten men. The above figures do not include foremen, but engineers only. In the case of one of the largest firms, the foundry, which employs two hundred men, has a technical staff consisting of a director, two assistant chemists, and two assistant electricians, to say nothing of the usual clerks and foremen. The only explanation of these large staffs is either that the work done per man is less than with us or that much greater care is given to experimental detail and general testing. While the first explanation is no doubt in part correct, it is to be feared that the second is the main cause.

Throughout some works small test-rooms were to be found scattered about, in which the various parts were carefully tested electrically as well as being merely "inspected." The result has been found to be a great saving of labour in the end.

It may be mentioned that owing to the excellent preliminary education obtained by all classes and to the great facilities given for technical education the competition for subordinate posts of this description is great and salaries are correspondingly small.

A point of interest is that in most drawing offices the draftsmen are distinct from what may be termed "calculators," who collect and prepare for use by the draftsmen the various data required. The mere recording of undigested results being of small value, the "calculator" would appear to be a most useful innovation.

Another cause for the large staffs is that, as previously stated, much

of the work done in this country by the consulting engineer is in Germany carried out by the contracting firm. As an example it may be mentioned that the design of the overhead permanent-way construction for the Berlin Elevated Railway was got out by Messrs. Siemens and Halske's drawing office. While the commercial and technical departments appear to be kept quite separate, the head of each department is chosen for his commercial as well as for his technical abilities. The sales department appears usually to be in touch with the works only through the medium of the firm's catalogue. The staff hours are from seven to seven and a half hours per day.

c. Labour.—Much difference of opinion seems to exist as to whether the German mechanic shows, or does not show, that soldier-like smartness and discipline with which he is usually credited. It was generally acknowledged that the output per man is less than that in England, while a considerable time seems to be wasted both in getting to work and in leaving off. Time-recorders were noticeable in nearly all the shops visited.

As to the hours of working, in Berlin itself nine or ten hours, with two hours off in the middle of the day, would appear to be the rule. In the outskirts of the town there is a nine or ten hours day, with two breaks, of three-quarters of an hour and half an hour respectively, while in the country eleven and twelve hours' work is still usual.

Little information is available as to the rate of wages earned by mechanics, but the following wages paid at the Berlin Central Station, working ten-hour shifts, may be of interest :—

Drivers and dynamo attendants receive 4d. to $4\frac{3}{4}$d. per hour.
Stokers, $4\frac{1}{4}$d. to $4\frac{1}{2}$d. per hour.
Switchboard attendants, $4\frac{4}{5}$d. to $5\frac{1}{2}$d. per hour.
Unskilled labour, $3\frac{3}{5}$d. per hour.

It may be mentioned that dynamo attendants and drivers are not above cleaning their dynamos and engines, and even scrubbing the floors of the engine-rooms. Piece-work seems to be very little used, day-work being almost universal. As a rule each man appears to work two machine tools, while in one instance a man was attending to no less than six. Female labour is extensively employed, but no data as to wages are available.

d. Treatment of Employés.—Large and comfortable dining-rooms, etc., are invariably set apart for the staff, but the most noticeable feature is the great care and thought devoted to the safety and comfort of the men. First, every precaution is taken in the way of guarding and fencing in the machines, the law in this respect being very stringent; and, secondly, every convenience is provided to enable the men to wash and get tidy before leaving the works. Besides washing arrangements, at various points about the works, a locker (preferably provided with wire netting sides so as to be open to inspection) is allotted to each man in which to leave his clothes, and one firm at least allows its men ten minutes of its own time for washing, etc. Reading-rooms and various clubs are organised, and in winter coffee can be obtained in each shop. The catering for the latter, which was under-

taken at first by the firm, has since in most cases been taken over by the men.

e. Machine Tools. — Most of the works are well equipped with machine tools capable of dealing efficiently with large work, but the tools for medium-sized work appear less suitable and not as a rule particularly well handled. There was an almost entire absence of automatic machinery, which, considering the large size of the works and the high pitch to which standardization has been pushed, would appear strange were it not for the low rate of wages which prevails. What machine tools were seen appeared to be built on the American lines of cheapness combined with strength sufficient for a few years, after which new and improved tools would be bought.

A neat magnet for holding iron castings on to a milling or planing machine was shown. It consisted of an electro-magnet, the poles of which were cut into the shape of teeth and almost touched one another, being kept apart by a strip of brass following the curve of the teeth. The work was subsequently demagnetised by an alternating current. A similar arrangement was seen in the form of a magnetic lath chuck.

In one of the works the counter shafting, driving lathes, etc., was all so fixed as to be readily movable along girders fixed to the ceiling, so that it could be moved to suit new machines as required.

f. Driving of Shops.—The usual practice would appear to be to use direct-current motors for this purpose, though the A.E.G. employ three-phase motors throughout, even for cranes, where a torque of two and a half to three times the normal is said to be obtained at starting without an excessive current. Whether the load is rigidly coupled to the motor or is driven through a springy coupling could not be definitely ascertained.

Small induction motors have as a rule short-circuited rotors and wire resistances in the stator, while large motors are started by liquid resistances, usually in the rotor circuit. These resistances generally consist of lead plates dipping into iron vessels containing the electrolyte which forms the neutral point of the system. When right down three switch contacts short circuit the whole resistance. A solution of soda is the liquid most generally used. Although the more general practice seems to be to employ a separate motor for each machine, some prominent exceptions were noticed. The feature of the machine tools at the Dresden Railway repairing shops were the speed cones. One set of cones is mounted on an adjustable frame which can be screwed up nearer to the second cones when required, so as to leave the belt slack for changing. The drive is in this case only two to three feet.

As regards motor starting switches, there appears to be more metal employed than is usual either in this country or in America. Less attention is given to finish, but the whole construction seems more massive. In the case of one particular crane starter, the switch contacts consisted of blocks of carbon and copper pressed into a solid mass.

g. Miscellaneous.—The drawings employed in the shops of one firm were inked and coloured and mounted upon thick mill-board about 4 feet square. In most of the other works visited, unmounted blue

prints, say 3 feet by 2 feet, were used. In one works neat celluloid cases were used, into which the drawings could be slipped and so kept clean.

The general impression gathered appears to be that everything looked as though it had been specially made for the particular purpose in view, and not simply built up out of materials at hand. In other words, nothing in the nature of a make-shift was to be observed.

Different works appeared to have had different objects in view, some seeming to strive after neatness and workmanlike finish, others after solidity, and others again after cheapness of manufacture. Throughout it was noticeable that less attention was given to minute details of heating and efficiency, such as often loom so large in our own specifications, but rather to general adaptability, price being considered at any rate as an important feature if not as the most important feature.

As regards fittings and wiring, the former appeared on the whole rather flimsy and "cheap," while the latter, though perhaps safe, was as a rule, to say the least of it, unsightly, consisting as it did almost exclusively either of metal pipes or of wires slung on porcelain insulators, the latter being often found even in private houses.

3. Design, etc.

a. Switchboards.—Nothing in the way of manufacture would appear to call for special notice except perhaps the electrically or benzine heated soldering-irons, used in some cases, the handle of the latter forming a reservoir for the benzine. Some small motor-driven portable drills were seen at work drilling marble slabs, the weight of the motor, which rested upon the slab, exerting sufficient pressure to press the drill home.

White marble slabs are almost exclusively used, the joints being either left exposed or being covered up by half-round strips of brass fixed against them.

High-tension fittings were mounted upon porcelain insulators, and in the case of high-tension switches, which were usually fixed behind the board with insulated levers passing through to the front, very long breaks were allowed. That for 3,000 volts would be 10 to 15 inches, and for 10,000 volts 20 to 30 inches as an average.

A heavy current fuse for 9,000 amperes at 220 volts was shown which consisted of eight or ten "presspahn" tubes, each with a copper wire passing through it, and all connected in parallel, the whole being contained in an outer protecting glass tube 2½ inches in diameter. Some high-tension fuses were seen constructed on the same principle, only having glass tubes in place of "*presspahn.*" In this connection the so-called *Stoepsel* (plug) fuses should be mentioned. The fuse itself is mounted in a small round box fitted with an Edison screw cap, so that by merely screwing it into place the fuse is inserted in circuit. Several ingenious methods are employed to render these fuses more interchangeable. The usual practice seemed to be to fix all switches etc., in a room behind the board, while regulating resistances are placed in a cellar below the switchboard gallery.

As regards measuring instruments, the most noticeable feature was perhaps the want of originality in adapting them to modern requirements. Whilst in this country edgewise and illuminated dial instruments have been long used, nothing but round dials, 6 inches and 8 inches in diameter, were to be seen. A very large number of hot-wire ammeters and voltmeters were in use, but the general opinion appeared to be that now that satisfactory dead-beat instruments for alternating currents can be obtained, they will no longer be so extensively employed. The entire absence of all recording instruments was very noticeable. Most of the alternating-current boards were provided with round, direct-reading wattmeters—a practice which might well be copied in this country.

b. Direct-current Dynamos and Motors.—Although the direct-current dynamo occupies a place of comparatively small importance in Germany, it is evident that its design has received very careful study, and great uniformity both as regards manufacture and design is noticeable. Increase in diameter and reduction in armature length seems to be the general tendency at the present time.

Whilst it is impossible to go into detail, a few of the main points noticeable may be enumerated. With one exception paper is used as the insulating material for armature core plates. Many laminated poles were met with, the laminations being about $\frac{1}{16}$ of an inch thick. The whole armature and commutator were always well ventilated, and usually a clear hole was left right through from end to end. Formers for small machines are usually made of some such material as presspahn or stabilit, while for larger machines zinc is usually employed. Wood flanges are never used. One firm builds up its armature core plates and mills out the slots afterwards; if this is done dry there are said to be no evil effects due to eddy currents. Multipolar machines are almost universally series coupled, so as to avoid cross currents arising from unequal pole strengths. When heavy currents have to be carried, two or three series coupled windings are connected in parallel. With the exception of one firm, cast steel is almost universally used in place of cast iron except in very small sizes. Almost all the armature coils are wound upon frames ready for slipping into place, and the taping is done by a neat machine worked by a small motor.

c. Alternators and Alternating-current Motors.—The methods of manufacture and design in the case of these machines appear to be much more tentative and experimental than is the case with direct-current machines. Stationary external armatures are universal, while many magnets are wound with copper strip on edge left bare on the outer surface and insulated by "*presspahn*" or some similar material. The winding of these coils is a matter of considerable difficulty, but if well done they have a neat appearance and the cooling surface is of course very effective. The armature windings are usually threaded through micanite tubes extending in the case of high-tension machines some two or three inches at either end.

Leblanc "Amortisseurs" are much used to improve parallel running, but the short-circuit pieces only extend through the width of a single pole and not from pole to pole as was at one time usual. The

same effect is produced in some cases, though of course less efficiently, by the use of massive pole pieces. As regards parallel running it may be remarked that it is most unusual to connect an unloaded machine on to the 'bus-bars, an artificial load being still almost always used.

The tendency now appears to be to "wind" the rotors of even the smallest induction motors, and even when short-circuited rotors are used the "squirrel cage" is often replaced by a winding in which the current has to pass through two or three turns in succession. In one firm at least a careful test is made by means of a lamp for contact between the core plates and the bolts holding them together.

The "A.E.G." have lately introduced a novel method of holding the armature plates of alternators; in place of the massive cast iron or cast-steel frames into which the core plates are usually fixed, two rings, one at either side and bolted through, are employed. These carry the necessary feet for holding down the machine, and are strengthened by six or eight tie rods forming chords to the circle. This lightens the machine and gives a larger cooling surface to the core. A large three-phase machine of this type is running at the A.E.G. Supply Station, giving 1,100 kilowatts at 107 revolutions per minute. It is said that by unscrewing two of the tie rods, together with the clamps on the cast-iron rings, it is possible to lift off the top half without fear of springing. Further, as the machine gets hot the armature discs expand more than the tie rods, and the only effect is, therefore, to stiffen the whole structure.

In conclusion, the Committee records its thanks to its reporters: Messrs. L. Andrews, H. W. Clothier, C. Day, K. Edgcumbe, A. H. Foyster, H. A. Mavor, and P. W. Sankey.

REPORT OF THE COMMITTEE ON TELEGRAPHS AND TELEPHONES TO THE COUNCIL OF THE INSTITUTION OF ELECTRICAL ENGINEERS ON THE VISIT OF THE INSTITUTION TO GERMANY IN 1901.

The members invited to report on telephones visited the Berlin Exchange, where a flat board is in use, arranged for 16,000 subscribers. This board is similar to that exhibited by Messrs. Siemens & Halske in the Paris Exhibition and is divided into sections each about 6 feet in length by 4 feet wide, to which the whole of the 16,000 subscribers will finally be connected. Each section was in charge of six operators, and each operator attended to 100 subscribers.

The jack and indicator are combined, saving the space usually occupied by the separate indicator. The indicator consists of a white plunger, which becomes visible in the centre of the jack on the sub-

scriber calling the exchange. This plunger is depressed out of sight by the insertion of a plug in the jack.

The multiple jacks used can be individually removed from the under side of the board for cleaning or repairs and easily reinserted by the use of a special tool, thus saving the necessity for removing the whole strip for repair to a single jack.

The rates of charge are as follows :—

Flat Rate.

M. 180. a year per line for conversations in Berlin and the following suburbs, called "Vororte" :—Adlershof, Charlottenburg, Friedenau, Friedrichsberg, near Berlin, Neu-Weissensee, Nieder-Schöneweide, Mühlenbeck (Bez. Berlin), Pankow bei Berlin, Reinickendorf (Ost), Rixdorf, Rummelsburg bei Berlin, Tempelhof, Wilmersdorf bei Berlin.

M. 200. a year per line for conversations in Berlin, in the "Vororte" and the following suburbs called "Nachbarorte" :—Cöpenick, Friedrichshagen, Gross-Lichterfelde, Grünau, Hoppegarten, Ludwigsfelde, Neuenhagen, Nowawes-Neuendorf, Oranienburg, Potsdam, Spandau, Steglitz, Tegel, Wannsee, Zehlendorf.

Measured Service Rate, at 5 Pfg. each. (400 connections a year obligatory.)

M. 100. a year per line for Berlin and the suburbs called "Vororte."
M. ·05. extra for each connection to suburbs called "Nachbarorte."

Coin-in-the-Slot Machines.

M. ·20. for 3 minutes in Berlin and the "Vororte."
M. ·25. „ 3 „ in Berlin and the "Nachbarorte."

About 25 per cent. of the present subscribers are on the toll rate and 75 per cent. on the flat rate.

It was stated that each operator can attend to from 100 to 160 subscribers on the flat rate, and the average number of calls per subscriber per day is given as about sixteen. On the toll rate each operator can attend to from 250 subscribers, and the average number of calls per subscriber per day is stated to be two.

In the larger towns coin-in-the-slot telephone apparatus for the general public had been largely introduced.

As regards protection between traction overhead wires and telegraph and telephone wires, while guard wires were used in some places, guard nets seemed to be favoured in others. These had a wide mesh, perhaps 9 inches to 1 foot. In Hanover, on the other hand, some of the span wires for the trolley wire itself were attached to the iron telegraph posts.

The telephone service in Berlin is discontinued when thunderstorms are threatening.

Mr. W. H. PATCHELL: One very important item which has been missed from the Report, because no record of it from our detailed reporters has reached us, is the Ems-Dortmund Canal. I have placed on the table a book which acted as a sort of guide-book when the German Emperor took some of his warships through the Canal. It is very interesting to us, both electrically and as a magnificent piece of civil engineering; the motor power for the ship lift is wholly electrical. At the present time the dynamos are driven by steam engines. Later on, when the Canal is complete, it is proposed to put turbines at the power station and drive them with the water which will run through the Canal, due to the difference in level from the two points in the Rhine which the Canal will tap; so that they will get a constant flow of water sufficient, with the addition of a battery of accumulators, to supply all the motive power to work the ship-lift. The Canal will then be practically self-acting! The ship-lift is an enormous basin or tank of 3,000 tons carrying capacity, with five floats, each of 600 tons, which are submerged, so that it is practically balanced. When a ship is to be lifted to the higher level, nothing remains to be done but to let it into this huge tank, shut the gates at the ends which are made tight by india-rubber seals, then start the motor at the top. This motor drives a lay shaft, which goes the whole length of the top of the tank-frame. There are six long screws, 26 metres long and 300 millimeters diameter, with a 100-millimetre hole through them. These screws are worked by the motor, and engage in loose nuts on the sides of the tank, so that by turning these screws up goes the ship. The ship-lift was worked for my inspection, and it took just two minutes and two seconds going from the bottom to the top, and from the top to the bottom. It is rather impressive to see this huge lift worked by a small motor. The starting current is about 400 amperes, the running current 250, with a pressure of 235 volts; and that for lifting 3,000 tons is a triumph for civil and electrical engineering. As a mechanical piece of work the ship-lift is most impressive. But what struck me most of all was the screws. They must have some good tackle in the machine shop to make screws 26 metres long and 300 millimetres diameter, if they can turn them out so satisfactorily. I should like to mention another matter which is referred to in one of the reports—the water-tight motors which are used for pumping. Through the kindness of Messrs. Lahmeyer, who also arranged for me the inspection of the Ems-Dortmund Canal, I was enabled to see one of their motors down at the bottom of the Caternberg coal mine at Zollverein. We went down 400 metres to see it, and there we found this three-phase motor. At first sight it looked like a horizontal steam engine, with two cylinders and the fly-wheel in the middle. The cylinders, of course, are the pumps which are driven direct off the motor by cranks. The motor runs at 60 revolutions a minute, and is three-phase, 700 volts pressure. The starting is very interesting. When they want to start the pump which lifts the water direct in one lift of 400 metres up to the top of the mine the engine at the top driving the dynamo is started very slowly. There is a sort of short-circuit valve on the head valve of the pump, and also

Mr. Patchell. on the suction valve; these are opened letting a little water back, and pulling the pump over the centre. They then shut the valve, telephone up to the engine-room to quicken up the speed of the engine on the bank, and the pump runs away. The parts of that motor, which I was informed by one of Messrs. Lahmeyer's engineers was something like 18 feet across, were all got down the pit in very small sections. It is a triumph of electrical engineering to see that motor, which I was told—not by the engineers, but by the men who had bought and paid for it—had worked without a hitch since the first day it was started.

I have a large number of photographs, several of which I collected in Germany; and the number has been very largely increased by the kindness of Messrs. Lahmeyer's London house. There is also at the corner of the table a book on the Dortmund works and a book on the Wiesbaden works, in which are photographs and cuts of the works, which I am sure you will find of interest.

Colonel Crompton. Colonel R. E. CROMPTON: I should like to add that it is impossible for us to avoid noticing the fact that our hosts at the time they were showing us their magnificent works were then face to face with a great financial crisis. I think we ought to put on record how plucky it was of them to take us round in the way they did and to put a brave face on it at the time when they were all very much depressed by the general collapse of mercantile affairs in Germany. Although this was very hard upon them, it gave us the advantage of seeing them at work in the stress of a very hard time, and that is a chance which is very seldom afforded to an inspecting party such as we were. But I think it makes all the more clear how grateful we ought to be to those gentlemen who never varied in their attentions, never varied in the courtesy with which they explained every important detail to us. My friend, Mr. Siemens, tells me that he wishes to say that also when he comes to speak. But I do not think it can be repeated too often, because I think in cases of this kind, although we are engineers of two nations, those of one nation should sympathise with those of the other when they are passing through such a crisis as Germany has recently passed through. We saw those magnificent works and we also saw the other side of the picture, *i.e.*, what their heavy capital expenditure entailed on them at the time when work became slack. Therefore, the lesson that we have to learn from our German visit ought not to be lost on those amongst us who have to study these things. As in the case of the last speaker, I myself and those who reported will be very glad to answer any questions that arise in the course of the discussion.

The President. The PRESIDENT: I would like Mr. Alexander Siemens, who was good enough to act as leader to the members in the course of their visit to Germany, to open the discussion on these most interesting reports.

Mr. Siemens. Mr. ALEXANDER SIEMENS: As Colonel Crompton has already indicated to you, the President was good enough to tell me beforehand that he would call upon me. I thought that as I had acted as leader it would be fitting for me that I should open the discussion by repeating the thanks which I have already had the pleasure to express to Herr Rathenau in Glasgow, when we happened to be together there, for the

uniform kindness we have met with in Germany during a distressing time for them and during a time when, for other reasons, one might perhaps have thought that there would not be a very friendly feeling to Englishmen. But all those who went on that tour would agree with me that nothing could have exceeded the kindness with which we were treated. A good many of the firms which received us took a great deal of trouble to show their appliances and methods to the members. The arrangements for our convenience which were made by the German firms were perfect of their kind, especially in Berlin, where we were nearly worked off our feet in order to see as much of the interesting electrical installations which are there as we possibly could in the limited time. The Verband Deutscher Elektrotechniker who invited us to their meetings at Dresden were also very kind. That some of our members did not understand German and could not follow the proceedings was to be regretted, but Dresden is a town where they could spend their time very usefully and very agreeably, even if they did not listen to technical papers. The various works which we saw there were extremely interesting. I should have thought that the Committee might have called attention to the station which was made to light and heat the royal palace in Dresden and also the famous picture galleries. It was, of course, of the greatest possible necessity that all these buildings should be thoroughly lighted and thoroughly warmed and at the same time that the danger of fire should be avoided as much as possible. Quite a party of us saw the central station where the heating and lighting is done and passed through the tunnels which were made from that station to the various galleries where the steam pipes for heating and the electric lines for lighting were all brought from the central station to the various buildings. As such a question of how to heat and light a building with the greatest security against fire frequently crops up here in England, that installation was an extremely interesting one; it was very well thought out and completed. In the paper reference has been made to the financial position and to the different systems which prevail in Germany of the banks being greatly interested in industrial undertakings. In very close connection with that subject is the circumstance which Mr. Patchell mentioned—that manufacturing firms have undertakings, central stations in various places, and work them, providing the capital and doing the business as well. That is really the system which has led to this crisis, and which I for one do not approve of at all. I think the manufacturing business and the exploiting business are totally different things requiring totally different capacities—I mean mental capacities—and therefore they ought to be kept entirely separate. I think if we do not follow the German practice in those respects we shall not go wrong. One of the first things we saw in Germany was the electric tramway in Hanover. That is extremely interesting because it is a sort of combination light railway and tramway. The lines have been extended from Hanover as far as Hildesheim. There is, roughly speaking, an outer circle of tramways, I think nearly five miles out of Hanover, and there are numerous radial lines which connect the circle with the town, and the

Mr. Siemens.

Mr. Siemens. produce from the country is brought into the town by these tramways and brought direct into the markets. Up to now the town of Hanover objected to the overhead system in the town, and to solve the difficulty the company is running their trams with accumulators in the inside of the town. I mention this because Hanover has been held up so very often as a good example of how accumulators can be successfully employed, and will work very well and can be charged while the tram is running on the overhead system outside the town or in the suburbs. Some months ago, however, the company petitioned the town to allow them to bring the overhead system through all the streets, confessing thereby that the system of accumulators has been a failure in practice. I think that is an extremely important point, because some people have blamed the County Council that they have not tried the Hanover accumulator system here in London instead of going in for the underground conduit. The system in Hanover has practically proved a failure, and not only that, but I have just heard that the company has got into difficulties and that they have been compelled to call up some further capital—they had the capital still to fall back upon—but anyhow it is thoroughly proved that that accumulator system in Hanover has failed.

It is perhaps interesting to mention that those cars which we saw at the "A. E. G." works in Berlin, and also at Siemens and Halske, and which were destined to be tried on the military railway at Zossen, at high speeds, have been in use since. I think the highest speed obtained has been 150 kilometres per hour—about 94 or 95 miles per hour. Of course, the speeds have been increased very gradually; they have, on the whole, been extremely successful. They had, of course, small failures, but the interesting part is that some experiments which had been made beforehand about air resistance, in connection with which I will refer you to a paper read before the Civil Engineers for further details—those experiments have been confirmed in actual practice by the resistance which the cars really showed during the runs.

Then I would call attention to another phase of German electrical engineering, namely, the telephone business. You heard that under the flat rate system of Berlin the calls from subscribers amounted up to sixteen a day. This is very high, and this very frequent use of the telephone results from the fact that it has been very much more adopted in Germany than it has been here. Thus it is well known that nearly all private houses have a telephone, that, of course, all tradespeople have one, and that a lot of the housewife's work is done by telephone in Germany.

I was not present at the Ems-Dortmund Canal, unfortunately, but I saw the overhead railway at Elberfeld. I must say it is very astonishing how beautifully and smoothly it works, but we must wait for the financial results before judging whether it is worth imitating or not.

Major-Gen. Webber

Major-General WEBBER: There are probably so many members present who accompanied the party on the excursion that I shall not occupy your time with more than one or two remarks. I wish simply to ask for information on certain matters on a subject, namely, the

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telephone service, which at present is very prominently before the public. I would like to point out to you that, according to the description given, the telephone in Berlin is apparently laid out on what may be called a radial system. The diameter of the inner area may be about three or four miles. Thus for a radius of two miles the charge is £9, and for a radius of one or two miles more, "Vororte," they only increase the rate by £1, namely, to £10. The rate for the "Nachbarorte" is not given. It would be interesting to know what it is. The Germans have, I believe, profited by the experience of other nations, and profited very much by the original mistakes as regards telephone work in this country. It looks as if they have learnt to regard telephony from the true point of view, namely, as essentially a means of local communication; and that as a service for distant communication (in which it is expected that provision should be made to enable us to speak to John o' Groats or Land's End), subscribers ought to pay far more than is now paid.

As regards *classification*, the Germans have, I understand, in some places adopted classification as applicable to time, that is to say, the hour at which you use the telephone during the twenty-four, thus distributing the load-factor on the wires in a way which ought to have been undertaken long ago in telegraph work, and I should like to see it adopted here in telephone work. Thus the toll-rate should be much less during the idle hours than during the busy hours of the day. My questions are more in the form of suggestions. I hope there may be a few minutes left at the end of the discussion to enable Mr. Kingsbury or those who reported to give a few more details than are contained in their short report.

Mr. Edgcumbe.

Mr. K. EDGCUMBE: There is one point I should like to touch upon, and that is in connection with the testing of gas engines. We were shown some rather interesting magnetic brakes at Messrs. Körtings' works. They consisted of electromagnets revolving inside an outer cast-iron yoke, through which water circulated. The revolving magnets generated eddy currents in the yoke, and consequently formed a brake to the gas engine. It seemed to me that it was rather a rough-and-ready way of doing it. Of course they took the temperature of the water, and so arrived, I suppose, at somewhere near the temperature of the iron itself; but when one comes to think that the increase of resistance of iron is something like ½ per cent. per degree centigrade, it would seem probable that the inaccuracy due to this cause would be even greater than that introduced by belting on to a dynamo in the ordinary way. There were some other magnetic brakes shown at Messrs. Siemens and Halske's works for small motors, in which a copper disc revolved between magnets. In that case the torque of the discs was balanced by an adjustable weight-arm, and consequently the readings were absolute.

There seems to be a good deal of difference of opinion as to whether the banking system is good or bad for the industry in general. One thing seems certain, however, and that is that it makes it difficult to properly estimate the value of various plants. Experiments must come in a good deal. When one firm has been carrying out the work and

Mr. Edgcumbe.

also financing it, and in fact is responsible in every way, there is rather a tendency for that firm to launch out into experiments. That, of course, is a first-class thing for the industry in general, but whether it is a financial success is perhaps a little doubtful. Also I think the results are made less public than they are with us. If there is any failure at first it can easily be tinkered up, and the final job is invariably made a success, but whether that stage is reached straight off is a little questionable.

It would be of great advantage if some speakers could tell us about the labour question in Germany. No doubt every one has been reading lately the articles and letters in the *Times* on the subject, and it would be interesting if we could be told what effects trade unions are having in Germany. It would also be interesting to know what the employers' liability is there, and how far the men have their own sick clubs, old-age pensions, and so on.

Mr. Hooghwinkel.

Mr. G. Hooghwinkel: I should like to be allowed to submit a few remarks with reference to the paragraph in the report of the Committee on Traction, Light, and Power, which refers to the use of an uninsulated middle wire. This system is in almost universal use in Germany—in fact most of the modern lighting schemes are laid out with this arrangement for the neutral wire. It is, moreover, almost always specified by the Local Authorities in German cities and towns, and is adopted whether traction schemes already exist or not. I may also mention that on no occasion, to my knowledge, has the system of an uninsulated middle wire been opposed by the Postal or Telephone Authorities, which bodies in Germany are even more exacting than in this country.

It is the practice in England to lay the neutral conductor, in three-wire continuous current distributions, of a section equal to about 50 per cent. of the outers, and this size has been more or less standardised by the cable makers. On the Continent a proportion of about 25 per cent. for the neutral conductor is the rule, and as it can be proved that this is quite sufficient in a well-designed network, considerable reduction of capital cost could be effected by adopting in this country a system of bare neutral wires with the approval of the Board of Trade.

Acting on my suggestions, the Company with which I am associated is now approaching the Board of Trade on this point. It therefore seems worth while to point out a few of the advantages which this system offers.

The chief points are: (1) Greater reliability in working. (2) Cheapness of distributing mains. (3) Cheaper and easier house service connections. (4) Facility in laying distributing cables both sides of a street without greatly increased capital expenditure. The middle wire can be readily divided and taken down each side of the street together with one of the outers.

As the advantages set out under (2), (3), and (4) are obvious, there only remains to investigate (1).

The allowable loss of volts in the middle wire over its entire length may be taken as *three volts* if no great number of arc lamps are in the circuit. In the latter case it is usual only to allow a loss of volts on the

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middle wire equal to *one volt.* With a difference of pressure of three volts no danger to gas or water-pipes or of telephone disturbances is possible, because practically no current passes through the earth. If the middle wire is too small, a portion of the neutral currents will find its way through the earth, in which case a bare neutral wire will begin to get oxidised. Other things being equal, the earth currents or leakage currents become smaller, the less the potential differences between various points in the middle wire, and also the smaller the metal surface of the middle wire in contact with earth, and the larger the extent of the network in one direction; that is to say, for elongated networks a greater loss of voltage can be allowed in the middle wire than in shorter networks. However, it is necessary to calculate a bare middle wire with some margin, not only to reduce the drop of voltage but also to compensate for the loss of section due to oxidation. The advantages of a bare middle wire as against an insulated one will be evident from the following observations: It is a well-known fact that, given two equally well-insulated leads, the negative one shows after the same time a much lower insulation, which can at times reach such limits that the negative finally goes to earth (osmosis). When, then, an insulated middle wire is used, the negative outer shows in time a proportionately bad insulation, the insulation faults mostly arising in the houses. If a bare middle wire is used, such faults may arise, *but they cannot last*, because, owing to the earth on the middle wire, the fuses in the respective outers go. Then before the light can again be set right, the faults have to be repaired. Thus, a bare middle wire offers a guarantee that faults in the outers will not remain unlocated or unrepaired.

As, however, in an installation of several thousand lamps it is impossible practically to carry out a systematic control of the insulation (except through the automatic action of the fuses with a bare middle wire), it is necessary *in the case of an insulated middle wire* to remember that the negative lead will in time have a more or less complete earth at certain points, as practice has shown in many towns. As long as the insulation of the two other leads (positive outer and middle wire) remains good, this circumstance can only cause *disturbances in telephones* in the form of leakages of current from one faulty spot to another on the negative lead, in proportion to the differences of potentials. These potential differences, as a general rule, do not exceed two volts, so that these disturbances cannot be very considerable. These earth currents, however, will always be greater than the earth currents arising from a bare middle wire, as in the latter the differences of potentials are not two volts, but only a fraction of a volt. The circumstances, however, alter very much to the disadvantage of the insulated middle wire, if through any cause an insulation fault arises in it or in the positive outer lead. These earths might be removed from each other by the whole stretch of the distribution net, and if in the neighbourhood of these different points there were telephone connections with earth plates, the leakage currents would partly find their way into the respective telephone leads and apparatus. It is also to be remarked that if the places at which there are faults do not develop a complete earth, the leakages of current might very easily become serious enough to disturb the telephone

Mr. Hooghwinkel. working, but not serious enough to melt the fuses. In such cases it remains quite uncertain where the faulty points really lie until a systematic test of the cable network has been undertaken. The disturbance therefore does not indicate itself through the melting of the fuses, but remains on until, by means of a systematic and lengthy test, the faulty places are located and separated from the cable network. If now the middle wire is put to earth, the likely area within which earth currents can arise with insulation faults in the outers, and the length of time during which the disturbance can last, are considerably limited; and this limitation is the greater the larger the number of the points on the middle wire that have complete earth connection. If the middle wire is connected for its entire length direct to earth, the currents arising from insulation faults would, for the most part, pass from the faulty places to the nearest point of the middle wire, and would only utilise the earth in the second place—that is to say, in so far as the middle wire does not suffice to conduct the short-circuit current in its full strength. As the fuses immediately melt in this case, it results that this rush of current is limited to a few seconds, and can produce no lasting disturbance, as it would in the case of an insulated middle wire. Now, it must be remembered that the mere laying of the middle wire bare in order to attain for its entire length a good earth is not sufficient, for in dry places there is always a certain, even if very limited, insulation between the wire and the soil.

In order to attain as nearly as possible the above described ideal conditions, I recommend a connection of the middle wire and the armouring of the outer wire at intervals of about fifty yards by means of section wires. In the case of any damage to such an outer the short-circuit current would only find its way through a limited portion of the earth, and would chiefly go through the iron armouring and through the next section wire on to the middle wire.

The system described in the above has been successfully worked in about a hundred large towns on the Continent, among which may be mentioned Frankfurt, Bonn, Hamburg, Madrid, Barcelona, Genoa, Osnabrück, Bochum, Baden-Baden.

Mr. Gavey. Mr. J. Gavey: I have not very much to add to the report on telephones; I would merely remark that in a paper which I had the pleasure of reading before the Institution in November, 1900, I gave a general description of the switch which is referred to here. Those interested in obtaining further details might perhaps with advantage refer to a well-illustrated description of the system issued by Siemens and Halske. Perhaps I may state incidentally that Mr. Siemens, when he speaks of the number of conversations per diem in Berlin as sixteen, refers only to the flat-rate subscribers. But if he makes allowance for the measured-rate subscribers, who only average two talks per diem, I think it will be found that the average is reduced to 12·5 per diem per subscriber, and I have been told that this is exactly the average of the subscribers to the National London Company's system. If I am wrong on that point I daresay there is some gentleman representing the National Company here who can correct me. The most important portion of the report deals with the question of rates. I observe that

the inner rate in Berlin is now practically £9 per annum. A short time ago it was £7 10s., so that presumably the German administration have found that the lower rate did not pay them, and they have had to raise it to the figure now quoted. However, there is one point of some little interest, namely, that the measured service rate is practically very much that which has now been published by the Post Office for the Metropolitan district; in other words, if I render the currency rightly, it is an initial subscription of £5, plus a minimum charge of 20s. per annum; in other words it is £6 for 400 conversations. I need hardly remind you that the Post-Office rate for measured service within the London County Council area is £6 10s. for 360 conversations. This question of rates is one that has excited a great deal of public interest in London, and I am afraid that if I were to follow the promptings of the Old Adam in me I should be tempted to enter the arena, and to review the whole subject, which could be judged so impartially by the members of this technical Institution. I restrain my ardour for two reasons. First, I am afraid the question must at the outset be dealt with in another place, and secondly, it would take up much more time than is available to-night. I should like simply to make one remark, and it is this: There is only one London in the world; owing to its area and its huge population there is not another place where the problems to be solved, electrical, mechanical, and financial, can be equalled or can be compared with those which have to be dealt with in Greater London. Mr. Gavey.

Mr. D. H. KENNEDY: I should like to make a few remarks on the telephone question. With regard to the calls per operator, at the commencement of the report we read that each section is in charge of six operators, and each operator attends to one hundred subscribers. Further down it is stated that each operator can attend to from one hundred to one hundred and sixty subscribers on the flat rate, and that on the toll rate each operator can attend to from two hundred and fifty subscribers. I should like to ask whether those figures are the assumed maximum, for an operator, or whether they are obtained from actual working conditions. Also I think it would be of interest to telephone engineers to know whether the flat-rate subscribers are connected to separate boards, or whether they are mixed indiscriminately. It would also be interesting to know the proportion of calls for the busiest hour. The flat board usually involves a canopy. I think telephone engineers would be glad to know whether in Berlin they suffer abnormally from dust troubles owing to the facilities which a flat board offers for the dust to enter the jacks; and further whether they have abnormal troubles from worn pegs working loose, and thus causing premature disconnections. Another matter which arises in connection with the flat board and its canopy is the health question. We read that the multiple jack is attended to by six operators, and from the figures given it appears that on each side of the board there would be rows of young ladies spaced two feet apart in the one line, the two rows being four feet apart. It would be interesting to know whether it has been known to have any bad effect on the health of the operators. I believe it is a fact that in some large offices in this country, where operators at one Mr. Kennedy.

Mr. Kennedy.

time sat in rows facing one another, arrangements were made at great expense to alter the desks so that they all sat facing one way. I believe that was entirely owing to the health consideration.

Mr. Aitken.

Mr. W. AITKEN: I wish to ask a few questions and make a few remarks in connection with the telephone section. The Berlin board has a jack and indicator combined, and I should like to know if this is used for the clearing signals, as it does not seem to me to be suitable, as it would have to be mechanically replaced.

Then with regard to individually removing the multiple jacks, I do not think that is a thing very much to be desired. It is usual to remove them in strips of twenty. In regard to the number of calls per subscriber in the larger exchanges of London—the Avenue, for instance—there are 16·5 calls per flat-rate subscriber, and in Liverpool there are twenty.

In connection with the telephone area, the German area is, according to the gentleman who raised this question, from six to nine miles in diameter. What is London's? From Redhill to Waltham Cross—south to north—over thirty miles; from Kingston to Tilbury—west to east—is also over thirty miles, a little in favour of the London area as regards the territory over which it is possible to telephone. With reference to Mr. Kennedy's remarks, in no case in this country have the operators been removed from one side of a flat subscribers' switchboard. In the Berlin Board there is no canopy.

There is one remark in the early part of the paper in which I am interested. I was rather surprised that Mr. Crompton thought portable soldering irons heated by benzine a novelty or worthy of a special notice. In 1890 or 1891, a London firm made for me some of those instruments (the old Swedish torch with soldering bit attached) in accordance with a suggestion made by one of my staff, and they have been used very largely in telephone work. Particularly on trunk lines were they found invaluable, as it was very inconvenient to carry a fire pot, and formerly wires were frequently left unsoldered until a more convenient season.

Mr. Lorrain.

Mr. J. G. LORRAIN: I may point out that the argument of the last speaker on the question of telephone area is entirely misleading. It is not a question of the number of square miles of area, but of how that area is occupied. The telephone area in London is occupied by buildings, whereas in Berlin it is occupied in the centre by buildings, and as to the remainder by land which is not built upon. That makes an entirely different question of the whole matter. I quite agree with Mr. Gavey that no other telephone centre in the world can for a moment be compared with London, where the problem that has to be dealt with is *sui generis*.

Mr. Stöttner.

Mr. J. STÖTTNER: Much has been said about telephones, and I think it will not be out of the way if something is said about the remaining contents of the paper. There are a few discrepancies to which I should like to draw attention. In dealing with the rotary converters in Berlin it is stated that they have an output up to 800 kilowatts. The largest rotary converter running, which I do not think is mentioned here, is 1,250 kilowatts. The converters at the Berlin

Electricity Works are built by the Allgemeine Electricitäts Gesellschaft of Berlin. They are of three sizes, viz., 600, 1,100, and 1,250. Mr. Stöttner.

Then there is a note in the paper about paralleling machines, to the effect that they are usually loaded up with an artificial load before they are switched into circuit. In modern machines built by the Allgemeine Electricitäts Gesellschaft this is not necessary, either with direct or with three-phase current. In the former case the machine is simply brought up to the proper potential, and then switched on to the 'bus-bars; and in the latter case the machine is brought up to potential and into phase and switched on to the 'bus-bars without using any artificial load whatever. With regard to the statement that drivers at the Berlin central stations are paid 4½d. an hour, I do not think this is correct. The man we call a driver in England is called the *maschinenmeister* in Germany, and considers himself a very important person, who certainly would not work for 4½d. an hour. The average salary of the machine master runs up to about M.200 to M.250 per month. Further, I have not found that engine drivers are employed to scrub the floors. I remember very well that some years ago I had to supervise some repairs in the Berlin central stations, and found the men knew a good deal about the engines, and were very well acquainted with every part of the engine-room. The average standard wages in the works of Berlin firms for skilled mechanics are also higher than stated in the paper, being something like 40 to 45 pfg. per hour, which equals about 5d. to 5½d., but for smaller work piecework is mostly done, and the men earn considerably more. For instance, the controllers in the testing and drilling departments have monthly salaries, which at the Allgemeine Electricitäts Gesellschaft are certainly not below M.150 per month.

Mr. M. O'GORMAN (*communicated*): Some remarks upon the subject of cables may be of interest, in connection with the Report of the Committee on Manufacturing. German cable manufacture is generally conducted on more scientific, but also on more intricate and expensive, lines than the English manufacture, which, by excessive thrift, errs in the opposite direction. Mr. O'Gorman.

In the making of low and high-pressure cables, as distinct from extra-high-pressure, the English simple methods have every advantage and have been rewarded by great success. Nevertheless, competition is to be expected from Germany for several reasons :—

(i) The cheap rate of highly skilled technical labour.

(ii) The fact that it frequently pays to import Westphalian copper to London for cable-making.

(iii) The fact that only technical and physical impediments have to be met in Germany to the reduction of insulation thickness, and that then there is apparently no legal compulsion to use a supplemental conducting armour inside or outside the lead sheath of "extra high tension" cables. Furthermore, there do not appear to be any restrictions as to the size of a cable shop, a matter in which at least the London Building Acts hamper some of our manufactures.

(iv) The remarkably good grip of certain technical difficulties :—

(*a*) Whereas the weakness of high-tension insulations has, up to the

Mr. O'Gorman. present, been chiefly due to unavoidable dirt in manufacture, precautions of extraordinary elaborateness have been made to obtain cleanliness. Every machine head which is served by a compounding tank has an individual cowl and chimney. Special precautions are taken to remove volatilised hydrocarbons from the impregnating tanks, and fumes from the lead pots, which besides are frequently heated by petroleum fuel to avoid the presence of ash and dust.

(*b*) Great floor space is allowed, and excellent illumination. All these tend in the same direction.[1]

(*c*) Electric driving, again, is a great help in keeping down dirt and dust, and the number of belts is less than in most English factories, even when motor-driven.

(*d*) Jute and yarn, cotton, etc., are as far as possible used from the spool on which they are delivered, instead of being re-wound on to special bobbins for the machines. (This, however, is currently done in England now.)

(*e*) *Vacuum Drying.*—The essentially technical improvement in which the German cable industry is ahead of ours is the adoption of vacuum drying, and vacuum impregnating tanks.

By means of large cast-iron chambers, which are steam-heated, it is possible to remove all the free moisture from cellulose and similar material without ever raising the temperature higher than 220° F., and therefore without producing any of the partial decomposition of the cellulose accompanied by evolution of water which invariably attends heating at the usual 240° F. for lengthy periods in English cable factories. Decomposition of the cellulose by heat apparently depends on time, and the time for the perfect drying of high-tension cables by the vacuum process is reduced from about 70 hours to about 10 hours. This fact further enables a small vacuum drying chamber to deal with many times the amount of material that can be handled by a heated and ventilated chamber of the same dimensions. The hygroscopic state of the air in the drying chamber is indicated at any moment by a continuously-reading indicator, and the superior strength of the fibre which has not undergone the preliminary roasting may be expected to give valuable results. As practised in certain German works, vacuum drying is by no means mechanically perfect, and unnecessary labour and some loss of time appear to result from coiling the cable on flat shallow trays, without any very apparent advantage over the skeleton iron drum more usual here. This practice originally arose from the drying machines being primarily designed for sugar and confectionery purposes. When we adopt the vacuum principle these minor errors may be avoided.

Wire Drawing.—Only one English cable maker has adopted the important technical step allied to financial policy which is likely to have still more important effects as the industry grows, namely, the drawing of the copper wire. Unless a maker draws his own wire, he is compelled, in order to meet the variety and suddenness of the cable demand, to carry large stocks of copper from £30,000 to £50,000 worth permanently, and this locking-up of capital must be paid for by an

[1] Though the output of the A.E.G. Cable Works at Oberspree is for five lead presses, the area is 10,000 square metres.

increase on the price of the produce. It corresponds a little to the standing-by charges of electricity supply, and the remarkable cheapness of cables when bought in very large quantities is evidently due to this charge being, as it were, wiped out in the case of such very large orders. By installing wire-drawing mills, and purchasing only one or two stock sizes of copper wire, the variety of demand may be met without the delay of waiting for the wire-drawers' delivery, and yet without carrying a multiplicity of different sizes in large quantity. Furthermore, there is an incidental economy on the operations of winding and measuring. It is to be noted that to effect these economies it is not necessary to instal rolling mills dealing with pig copper, but only to instal such wire-drawing plant that copper of one single size can be stocked. Mr. O'Gorman.

Bobbins and Reels for Factory Use.—It was clear that the rapid variation in the class of cables sold, or other causes, had not allowed of the standardisation of the sizes of the bobbins and reels. This was the more surprising as the cable works visited were comparatively new. On the other hand, money seemed to be no object, and this may have led to a somewhat wasteful neglect of the fact that bobbins and reels represent a very considerable locking-up of capital. This defect is equally noticeable at home, but is as a general rule due to very different causes, such as the old-established nature of the business, and the amount of pioneer work effected here.

The *standardisation* of cable-sizes adopted in this country by the Cable Makers' Association, which will eventually be an economy not only to themselves, but to the makers of switchboard castings, pipes, conduits, etc., has been followed by a similar adoption of standards in Germany. The point of interest here is, however, that the body which corresponds to the I.E.E. (the Verband Deutscher Elektrotechniker) is a party to the standardisation. The Joint-Committee passed the resolution while the Institution was visiting Dresden.

Patents.—The German Patent System with its elaborate priority search is expected to be shortly imitated in this country, and in so far as this may be expected to result in the diminution of the number of useless papers which accumulate at the Patent Office, this has certain advantages. Nevertheless, it is not found that the German method is any better able than our present one to make possible the publication of inventions based upon the mixing of compounds for insulation or other similar purposes. The result is a number of secret recipes.

It is admitted that the discovery of chemical or mechanical mixtures having peculiar electrical qualities is of great use, and that publication would lead to very rapid progress. Indeed it is quite possible that the reason why no waterproof flexible substance other than gutta-percha has ever been found, may be largely attributed to the fact that all the independent workers in search of such a material are constantly covering the same ground instead of starting each where the other left off. The willingness with which the cable factories have undertaken a study of a new departure in cable design both in Germany and in England is remarkable, and in both countries quite a number of cable makers have begun to make experimental insulations with the capacity of the dielectric "graded" in accordance with the method suggested in the Journal of this Institution for 1901 (vol. 30, part 150, page 633).

Mr. O'Gorman. In conclusion, the German cable industry appears to be not so much ahead of ours in present work as in the seeds it has sown of important advances in the near future.

Mr. Cottam. Mr. G. H. COTTAM (*communicated*): *Körting Gas Engine.*—I am sorry to note that no reference has been made in the report in reference to this. Although I was prevented from thoroughly inspecting this gas engine, I was led to believe that in the near future we may get some class of explosive engine that would work so economically with producer gas or other agent as to supersede boilers and steam engines. It is sufficiently well known, I think, that superheated steam is much more used abroad than in this country, and for that reason has not received any special mention in the report. It may also be nothing new to the British public that the tramways are nearly all worked by electricity abroad. I was only able to remain until after the Berlin visit, but I scarcely saw any cars drawn by horses.

Buildings.—The design of the buildings for stations and workshops is certainly handsomer than those in this country; I noticed also that the brickwork in Berlin was better than we get ordinarily in London, and the pointing somewhat different. A remark has also been made in the report with regard to the arrangement of shops, as to whether it is more advantageous to build large works in one block or in separate detachments. Certainly the latter, where the ground is cheap and available, gives better facilities for ventilation and light, although costing more for transporting goods from one department to another.

Labour.—This paragraph on page 543 reads as follows:—"Much difference of opinion seems to exist as to whether the German mechanic shows, or does not show, that soldier-like smartness and discipline with which he is usually credited, etc." Now, I can speak from practical experience of some years abroad, and, as far as I have found, the military training is very beneficial to the men, both as regards orderliness, discipline, regularity and cleanliness, and it is almost an unknown thing for men to take time off for drunkenness or the keeping of "Saint Monday." It is also mentioned in this part of the report that a considerable time seems to be wasted both in getting to work and in leaving off. This is entirely against what I saw personally, as, instead of the men giving their time in at the gate of the yard, as is done in most factories here, and then loitering in the yard before starting work, there are time-recording instruments on every floor of the workshops, and the employés have to change their clothes before reaching and after leaving the working floor. There are no means for washing their hands in the works proper, but an elaborate arrangement for doing so outside, so that the employés have no occasion to leave the floor on which their work lies until meal times or at the close of the day, as tool and other stores are quite handy. I think this arrangement must be conducive to less loss of time during working hours.

Units Sold.—Is there not some error in the figures on page 539, as those given to me were more than double the figures stated, the units generated in Berlin being either 103 or 107 millions for the twelve months.

Treatment of Employés.—On some of the establishments I noticed

that they have baths, and supply each workman with a ticket entitling him to a bath once a week in the employer's time, probably arranged in this way owing to the difficulty in accommodating all the men at any one time, and in order to encourage cleanliness. Mr. Cottam.

Handling Castings.—In some of the shops it is the recognised rule that after a casting has been roughly milled or planed, and before the finishing cut is made, it is taken out into the yard to allow it to expand or contract as may be necessary, in order to prevent it warping after being finished, and I understood that it was found to be very beneficial in finishing such work as lathe beds, etc. If I remember correctly, the whole of the top of a lathe bed with two V-shaped grooves is shaped with a set of milling cutters direct from the rough casting, and without being touched with an ordinary planing tool. In one of the works I also saw a very neat arrangement in the form of a revolving table with a sand blast for cleaning the castings; and in the grinding shop, instead of each turner grinding his own tools, they have an elaborate arrangement for drawing off the dust, so that there shall be no detriment to the employés—in fact, in most of the shops the ventilation and heating is superior to those in the majority of shops I have seen in Great Britain.

There is one matter in the design of large engine and machine beds that I think our engine builders would do well to adopt, namely, the casting of a groove round the bottom of the bed plate to catch any drip of oil and water. This tends to keep the floor of an engine-room much cleaner, and minimises the amount of washing required.

Professor W. W. HALDANE GEE (*communicated*): I remained in Berlin after the Institute party had left, and was enabled to make a number of visits not in the official programme. At the Bergmann works I had the opportunity of seeing the manufacture of the paper tubing which is impregnated with a bituminous compound, and afterwards generally covered with thin sheet brass. This tubing is very largely used in Germany for electric light installations. One of the laboratories at the Manchester School of Technology has been wired to illustrate this system. My visits included a number of works employed in the manufacture of scientific and electro-technical instruments, and I came away with the general impression that this trade is being brought to a high state of perfection, and the work was being produced at a price which seems impossible in England. It is to be regretted that only a few of the party visited the Reichanstalt. This great institution is doing a fine work for science and the scientific trades of Germany. It is mentioned in the report that the taping of formed armature coils is performed by the help of a machine. I would direct the attention of dynamo-makers to the great saving of time, over the tedious taping by hand, that results. Prof. Gee.

Mr. A. H. FOYSTER (*communicated*): It was a disappointment to find that the Germans had not experimented further with mechanical stokers. The station superintendent in Berlin told me that they had tried one of the early types of English stokers, but it was not successful. I understood that the upkeep had been high, and from what we saw, and can gather from the illustrations of the generating stations supplied to us, the "verboten" against smoke does not press very heavily. The Mr. Foyster

Mr. Foyster. superintendent seemed to think that there was no gain in efficiency by using mechanical stokers.

Some doubt has been expressed as to the correctness of the figure of 40 pfennigs per hour as the rate of pay of engine drivers. The figure was given by the station superintendent, but I did not understand that he meant foremen, as he mentioned, as one of the advantages of the horizontal engine over the vertical, that the 3,000 H.P. verticals in the Luisenstrasse station took four drivers to attend to each while running, while the 3,000 H.P. horizontals only took two.

I think the figure of 7·2d., given on page 540 of the report, as the price per unit for arc lighting is incorrect. Allowing for half the lamps to be switched out at midnight, and adding the £6 for lamp hire, this would work out to about £45 per lamp per annum. This seems prohibitive. I think the error lies in a confusion between 60 pfennigs and 16 pfennigs. The latter rate per unit works out about £16 10s. per lamp per annum, which seems more reasonable.

I should like in conclusion to express a deep obligation to the German engineers for not only showing and explaining to us their works and machines, but also for the trouble they took in supplying us with figures and details regarding the management of their stations.

Mr. Leven. Mr. C. Leven (*communicated*): What I wish to point out is, that we have learned, from the trip to Germany, that on the Continent more multiphase- are used than continuous-current machines, and if only everybody in this country would understand that a multiphase machine is a good deal simpler than a continuous-current machine, far more multiphase work would be done in this country. As a matter of fact, multiphase machines are looked upon, by the large majority of people, as somewhat mysterious, and as so many engineers have not had any experience with these machines, they are not so popular nor used as much as they should be.

With regard to German finances, I wish to point out that German manufacturers of reputation and good standing have, as a rule, some financial house to back them, and these finance companies, as they are called, as a rule have done a great deal to further the interests of German manufacturers. At the same time, as it was shown last year, some of these Finance Companies who are, in reality, bankers, have lost a great deal of money through the trade depression in Germany, and particularly through many of the German Companies having undertaken large contracts, and, in many instances, received as payment too much paper and not sufficient cash, and hence the present depression.

Mr. Morris. Mr. J. T. Morris (*communicated*): In the recent German visit, quite a number of electric eddy-current brakes were noticed for testing machines when running on load. In Messrs. Körting Brothers' works a large brake capable of absorbing about 500 H.P., at 140 r.p.m. was seen being used for loading up a gas engine. A multipolar field revolved within a fixed cast-iron framework; the revolving field, approximately 6 feet in diameter, was supplied with continuous current through two slip-rings. This revolving field induced eddy-currents in the fixed cast-iron framework, which was provided with water circulation, by

means of which the temperature could be kept constant. In order to regulate the load, the exciting current can be adjusted. The brake has to be previously calibrated in order to determine the relation of load to exciting current for a given temperature of the field frame. Mr. Morris.

In this arrangement there does not appear to be any great advantage gained over the usual plan of employing a dynamo as load whose efficiency curve is known.

It is rather in small motor testing (2 H.P. and under) that the superiority of the electric eddy-current brake becomes evident. As is well known, in electricity meters, eddy-currents are very commonly employed as the retarding force. But for the thorough testing of small motors, it appears to be capable of a much higher degree of accuracy than the mechanical friction brake, being perfectly under control, and might with advantage be used more in the testing laboratory, if not also in the testing departments of manufacturing firms.

In the examples seen, a copper disc was attached to the shaft of the small motor, and a single horseshoe-shaped electro-magnet (or a pair) was arranged so that its poles embraced, without touching, the copper disc. The electro-magnet was supported on knife-edges and had an arm attached along which a sliding weight could be moved, so that the torque produced could be at once determined.

Mr. Percy S. Sheardown (*communicated*): It is very interesting to notice in the papers presented to us this evening, the individual points which impressed the writers as of most importance, and this will, I trust, apply also to the discussion. The features which impressed me most in the many interesting power-stations visited, were, first, the large number of big *single*-crank engines employed (direct coupled) to drive both alternators and direct-current machines; and secondly, the peculiar arrangement of generating sets at Messrs. Lahmeyer & Co.'s station at Wiesbaden. Mr. Sheardown

Direct-coupled *single*-crank engine sets *only*, were employed at both the large Dresden stations, at the Frankfort station, and also at the Wiesbaden combined station. At the latter station several of the engines were driving direct—a flywheel type three-phase alternator, a D.C. traction generator, and an exciter; each of the generators was large enough to load up the engine; they were not placed one on each side of the engine, but were, with the exciter, placed in line on one side.

With direct current always on the 'bus-bars, I was rather surprised to see separate exciters supplied; it also appeared a case in which a suitable friction clutch might be used with advantage, as with the engine on full load with one machine it appears uneconomical to be always running the other one light.

I note from the papers that the wages of the station employés are low; but as is often the case, when you get a thing cheaply, you compensate matters by being extravagant with it, and it appears to me from casual observation that there were a good many men employed in some of the stations we visited: for instance, at the transformer station (Schiller Platz) Frankfort, which I visited alone, there were

Mr. Sheardown.

some large motor generator sets and an accumulator battery to be looked after; three attendants appeared to be on duty, whereas at home you would not find more than one man, or a man and a boy. From this and other observations it appeared to me that the Germans lean more towards safety, than towards efficiency and low cost; for instance, at the Dresden tramway station I watched the total output meter for some time, it was varying from 1,400 to 2,000 amperes. There were two machines running to supply this load, each of which was rated at 1,570 amperes, but besides these two there was a third stand-by machine running light. This did not appear to me to be the most economical conditions, but I read in the paper before me that the city authorities own the station, but charge all the expenses of generating against the tramway company and then take a share in the profits, which explains matters somewhat.

I should like to have seen some figures relating to the cost of upkeep on the auxiliary accumulators used to run the tramcars through the principal streets in Berlin, Dresden, and other show cities. I was told by a good authority in Dresden that the cost of maintenance was enormous, and much reduced the profits.

Mr. Digby.

Mr. W. P. Digby (*communicated*): The reports of the Sectional Committees of the Institution on what was seen by those members of the Institution who visited Germany last summer are so interesting that one feels tempted to suggest that the Council should give one evening each winter to the consideration of a *résumé* from these Committees of the general trend of electrical engineering in Great Britain and abroad. I say this in appreciation of the interest and accuracy which characterise the reports now under consideration. Being at the time of writing still resident in Berlin, and having been a sharer in some of the Institution visits, I can only say, that had it not been for the splendid facilities then granted to us by our generous hosts, I should probably have left Berlin without an insight into the factories and manufacturing methods which have given that city her fine tramway, telephone, and lighting systems. My comments only pertain to the Berlin sections of the reports, and are only an extended endorsement of them.

My practical experience of the smoke regulations is that a great deal depends upon the district in which the chimney may be. In the poorer quarters but little trouble is occasioned by the police inspectors. What proportion of the soot and fogs of an English industrial town is due to domestic and what to manufacturing sources I cannot say, but in Berlin the latter is certainly very small. The vogue of the electric motor is such that for smaller factories isolated steam plants are almost unknown, so that the police have only a very few large smoke stacks to look after.

I should have been glad if the Committee on traction, light, and power distribution had been able to give any figures relative to the motor load in Berlin. Its extent would greatly surprise an English municipal engineer. I will give what I consider to be a typical instance. The smaller factories are rarely separate buildings; but one huge block with its large courtyard in the centre will contain the most diverse of small industries; tools, accumulators, furniture, pianofortes,

printing, and a brewery will each occupy their necessary number of flats. In these, in good times, perhaps a total of 1,000 hands will find employment, and the aggregate capacity of the motors will be 300 or 400 kilowatts. There are but few giant firms such as those who were our hosts, with an innumerable host of small businesses depending on electricity from the central stations for their motive-power. Mr. Digby.

The use of the accumulator on the car itself is greatly decreasing, being only used on a very few routes—mainly, towards Charlottenburg. The trolley wire has increased its extent in the city this year. There are a few miles of conduit system (side-slot), a new section at the Opern Platz having been recently opened. I have travelled to and from office on the electric cars four times a day for many months. The trolley continually leaves the wire, but I have seen no broken trolley wires. I have, however, several times noticed an arcing about the controller box. Passengers are allowed to stand on front and rear platforms. This 30 per cent. increase in carrying capacity does not counterbalance what would be gained by having double-decked cars. There are still a few horse-dragged cars left, which old cars are also used as trailers. The only accident I have seen was a broken axle on one of these trailers. Wooden strip is used as a guard against broken telephone or telegraph wires.

Perhaps it is not out of place to mention to the Institution that there is practically no telegraph service within the city; an excellent pneumatic tube service—called "Rohr Post"—is its successful and cheap substitute.

I entirely agree with the Manufacturing Committee as to the work done per man among a German staff. I hesitate to say that supervision and details are overdone, but men take longer over the work than would be required in England without providing the compensation of an average greater accuracy.

In regard to labour, the output per man is less, and after ten months' experience I consider the German workman is lacking in ingenuity and in initiative as compared with the North Country mechanic. Incidentally I would mention that the average fitter or machinist on any but repetition work has an unconquerable weakness for using a blue print or tracing as a template, instead of working to written dimensions. One great virtue the German workman has, even if he be slow in starting work, in that the smallness of the percentage of lost time throughout the whole year, and the complete absence of "Bank Holiday after-effects," are most pleasing. I consider the German the best timekeeper I have so far met. As for hours of labour, neither staff nor workmen have a Saturday half-holiday.

But to dilate on German economic conditions, and the relation, say, of the military system to factory organisation, would be to overstep the time and space apportionable to each member.

Mr. W. C. LAIDLER (*communicated*): The reports of the various Committees on our recent German visit form a valuable digest of the impressions received, although the impressions of the different Committees appear to me to differ in some respects. The report on traction seems to imply that polyphase motors are chiefly used for power in Mr. Laidler.

Mr. Laidler. workshops, whereas the report of the Committee on Manufacturing states that "the usual practice appears to be to use direct-current motors" for the driving of shops. This difference may be a wrong impression I have formed from the reading of the reports, or it may be due to the different members of the different Committees being respectively specially interested in one type or the other, and therefore specially on the look out for them.

With regard to the remarks of the Committee on Manufacturing (Part 2, section G.), it surely must have struck all of us that our German friends' method of wiring on porcelain insulators was admirably suited for workshops. The track of every wire was visible, and when neatly done appeared to the writer to be anything but unsightly. Of course, for private houses such a system is hardly the thing to our minds, but where a good sound job which can be easily repaired or altered is required the German system seems difficult to beat.

One other matter to which I should like to refer, is in connection with the milling of armature cores after assembly. This was the writer's practice a few years ago on all machines of his design, and at that time he carried out a series of tests with a view of ascertaining the best method of building and slotting the core. Four similar armature cores were prepared, the first smooth, the second built of plates ready slotted, the third slotted dry after building, and the fourth slotted with a wet tool after building. Each core was then run for four hours in the same field, and the rise in temperature carefully noted. The temperatures of the smooth core and that built of plates slotted before building were practically the same (the slotted core being rather lower owing to the fanning effect of the spokes); that of the core slotted dry was 5° F. above the first two and that of the core slotted wet 25° F. above the first two. This appears to show that with good, sharp tools and the armature core very solid it is permissible in certain cases to slot the core after building if the tool is used dry, although the best way, which is the writer's present method, is to use plates ready punched before assembly. At least one firm in this country uses plain discs which are slotted after building, then the core is stripped and each plate ground on a horizontal emery wheel, to do away with the possibility of any burr being left by the milling tool, after which the plates are reassembled. This, however, seems a very laborious and unnecessary process.

Mr. Roberts Mr. R. C. Roberts (*communicated*): To one who has been resident for some twelve months past in Germany and had the run of one of the largest of the works visited, the reports appear of exceptional interest and remarkable for their accuracy even in detail. A few points appear to have escaped notice, and are, I think, of sufficient interest to warrant the following remarks.

Tramcar, Light and Power Distribution.—*Prime Movers.* Some figures given at the central stations were: for Messrs. Sulzer's engines of about 4,000 H.P., pressure in H.P. cylinder, 210 lbs. per square inch or 14 atmospheres) at temperature of 300° C.; for the Görlitzer M.F. engines, 195 lbs. per square inch and 250° C. The latter makers jacket the I.P. and L.P. cyclinders with steam reduced from the mains.

The use of such high degrees of super-heat is unusual in this country, but little or no trouble has followed its adoption on the Continent, probably owing to careful experiment for the right metal to use for packing rings and attention to efficient lubrication and cooling of the piston. Super-heat is without a doubt the prime reason of the wonderfully low steam consumptions guaranteed and obtained by Continental firms. The 50° C. superheat mentioned in the report would correspond to a temperature of about 260°C., at 210 lbs. per square inch, hence Messrs. Sulzer super-heat about 90° C., if the above information is correct. The Görlitzer M.F. claim with their Colman valve gear a special advantage in governing. The gear being more a "hit" than a "trip" gear, the governor can become effective at any moment during the stroke. Mr. Roberts.

Generators. Continental experience with rotaries has been much the same as American, viz., that the machines can be made at 50 ∾ to work well on steady loads such as battery charging, etc., but that for traction work they are unsuitable. The latest set installed in Mariannenstrasse sub-station in Berlin is a dynamo driven by a three-phase induction motor. The set looks very big next to rotaries of the same capacity. The veering round from the rotary to the other extreme, the induction-motor set, and the omission of the synchronous motor is noteworthy, inasmuch as all the switchboards are supplied with phasemeters and gear for keeping the cos ϕ at or near unity, which is impossible when the induction type of motor is employed.

Motors. The three-phase induction motor has undoubtedly justified its adoption for shop driving purposes. The heavy starting current, with squirrel-cage rotors, which are generally employed with small machines, was at first a heavy tax, but the use of such starting devices as the A. E. G. Stufenanker and the Siemens and Halske Gegenschalter keep down the standing currents to within reasonable limits. The former device has a high- and a low-resistance rotor winding, the low-resistance winding being kept on open circuit till nearly full speed is reached. Neither of these devices can increase the starting torque, as the use of slip-rings and a non-inductive resistance in the rotor circuit does, but they are simpler and cheaper than the latter.

Tramways. Shortly after the Institution's visit to Berlin, Messrs. Siemens & Halske completed a short run across the Unter-den-Linden on their slotted-rail system. The arrangement was devised for use with trolley-cars in order to do away with batteries, which have certainly had but a qualified success in Berlin for tramway work. The car was so designed that an arm carrying a contact gear could be lowered through the slot and hitched on to the back of the car. At the time of viewing, men were stationed at each end of the run with the gear ready for attachment. The system seemed to work well.

Financial. After the Institution's visit, a tendency was noticeable in certain papers to criticise the somewhat lavish expenditure laid out on many of the works. An implication that the prevailing depression is connected with the method of arranging and running the works is liable to be misleading. Cleanliness and order are main features in cheap and rapid production, and it is questionable whether the extra amount spent on pure ornamentation is so great, and whether it does not repay

Mr. Roberts itself by the incentives it offers to employés to take a pride in keeping everything in ship-shape order. That there are too many big concerns is undeniable, bnt it is possible that some firms have felt the prevailing depression, not so much through their works, as through outside schemes which they have financed on somewhat speculative lines. At any rate it is noteworthy that one of the firms that are maintaining their position is conspicuous for the seemingly extravagant appointment of its works.

Staff. This word corresponds approximately to the German "Beamte." As regards general testing, very great care is certainly given to detail. The interested type of German engineer is extremely industrious at probing the ins and outs of his investigations, in fact the accumulation of even valuable detail becomes at times so great as to be only partially useful for the immediate purpose. The extent of scientific training is very marked, and also the knowledge of languages, especially English. If there is a fault it is the absence, or partial absence, of practical workshop training, among the electrical engineers especially, and experience has a tendency to become very specialised. German engineers are very interested and courteous in exchanging notes on engineering topics.

Labour. The men appear to be slow, but easily manageable, and there is a complete absence of "trouble" with them.

The report says "day work is almost universal." This must have been written under a misapprehension. At the A. E. G. piecework is certainly the rule, but as regards other works the Committee had the best opportunities for generalising.

Machine Tools. The report says, "There was an almost entire absence of automatic machinery." Are the Committee sure they saw all the machinery at the works visited?

Driving of Shops. As regards couplings for three-phase motors, it does not appear to be essential that these should be springy, though it may be advantageous.

Miscellaneous. Wiring. Metal piping can hardly be said to be exclusively used, as much "hart-gummi" or vulcanite tubing is in use for lighting purposes.

Switchboards. The report makes no mention of the ample space allowed at the back of the switchboards, and the extreme orderliness of the arrangements there. These are the principal points necessary to ensure safety in a high-tension system. All connections are arranged to be visible at sight, and shop mains are conducted neatly in convenient underground passages, facilitating inspection and decreasing liability to faults. The phasemeter is a very useful instrument for stations where cos ϕ is liable to be low, especially in sub-stations where the design permits the cos ϕ being raised to unity. I do not know that mathematical accuracy is claimed for it, but its utility is unquestionable.

Paralleling of Three-phase Alternators. The report implies that artificial loads when paralleling are universally employed. I never heard of any trouble in paralleling at the A. E. G., and saw machines of up to 4,500 H.P. thrown into parallel with perfect success, without any artificial loads being necessary, and with no visible disturbance of the voltage.

The paralleling of the rotaries is more difficult, and requires experience which may be dearly bought. When the necessary skill is once attained, the switching-in can be carried out with certainty. Mr. Roberts.

Miscellaneous. The relations existing between the heads of manufacturing firms and University professors seem to be of a most cordial character. This tends to the advantage of both, and the profession in general. It is due to this good-feeling that the A. E. G. has been enabled to develop and put on the market a patent electrically-driven express pump, a new system of wireless telegraphy, a waste-heat engine using SO_2 as the gaseous medium, and a well-known lamp, all of which are associated with names of University scientists.

Mr. Patchell.

Mr. PATCHELL in reply said: There is very little indeed for me to say. I quite agree with Mr. Siemens' regret that everything could not be brought within the four corners of the report. We had a great deal of material sent to us, more than we could possibly put into the pages of the Proceedings which we understood were at our disposal. So that unfortunately we had to omit among others the interesting example of lighting and heating in Dresden. With regard to accumulator cars in towns, I was told by a friend (I cannot vouch for the truth of it as I got it secondhand) that in Berlin the Emperor has issued a "verboten" against accumulator cars. They are so frequently stopped that he is going to have them stopped altogether. Mr. Hooghwinkel in dealing with the question of the bare middle wire mentioned that the size of cable adopted in this country is due to the cable manufacturers. I think he is in error in that statement. There are many consulting engineers in this country who are perfectly free, as Mr. Crompton said in his report, and can use whatever size of bare middle wire they please! I am very much obliged to Mr. Stöttner for correcting the figures as to the size of motor generators in Berlin—1,250 kilowatts instead of 800 is a very considerable increase.

Colonel Crompton.

Col. CROMPTON, R.E.: I do not think any questions of importance have been put to me except that I am made to say that the benzine soldering iron was a novelty. I did not intend anything of the kind. It was merely mentioned, as a matter of interest, that such things were used in common with a great many other things mentioned which were certainly not novelties. For instance, many of the high-tension fittings were mounted on porcelain, and we simply mentioned it in order to show how many good things were to be seen in Germany.

Mr. Kingsbury.

Mr. J. E. KINGSBURY, in reply, said: With reference to General Webber's remarks about the respective telephone areas of Berlin, I find that the "Vororte" area is of irregular formation. It has an extreme length of about 12 miles and an extreme breath of about 7 miles. The £9 rate thus covers a radius of not less than 3½ miles, and averaging somewhat more. The "Nachbarorte" area is very irregular in formation, varying from 6 miles to 30 miles from the centre of Berlin. General Webber is mistaken in thinking that the rate for this area is not given. It is stated to be M.200 per annum. I do not find any essential difference between the Berlin system of rates and those prevalent in London. The classification of the latter into the County Council area and the larger telephone area beyond the County Council

Mr. Kingsbury.

boundary is not very dissimilar to the Berlin area when the dimensions of the two cities are considered. Mr. Kennedy will notice that the Committee's report is somewhat specific. The report states what the reporters saw and what they were told. I gather that they saw one operator attending to one hundred subscribers, and I think it is specifically stated they were told that one operator could attend to a larger number. It is not unusual for an exchange to be overmanned, or, in such a case as this, overwomanned. It is not always that the work is done under stress. The idea that a canopy is necessary for a flat board is a mistaken one. While flat boards were originally furnished with canopies, there are a large number of them without; and this particular one—I did not see it in Berlin, but I saw a model of it in Paris, and I believe Mr. Gavey described it in his paper—had no canopy. With regard to the dust in the jacks and so on, I find that our reporters made no remarks on that subject; they had as much as they could do in the time at their disposal to give a broad and general outline rather than to go into too much detail. That the boards do suffer somewhat from dust in the jacks I think is obvious from the provision made to remove them readily. The health question as regards the flat board is somewhat a new one to me. We have discussed the question here in this room somewhat fully (this Journal, 1896, vol. 30, p. 300), and I do not propose to go into the question again now, but certainly if all the operators sit on one side of a flat board, the only advantage ever claimed for it is taken away. I regret that I cannot give any information as to the health of the operators, but as so few flat boards now remain in use in England, and those not large, it would probably be difficult to draw reasonable conclusions from the exchanges in question. With reference to any comparisons which may be made with London, I think that it cannot be too strongly emphasised that, as Mr. Gavey said, there is only one London in size and circumstance, and that, telephonically, as Mr. Lorrain observed, the problem to be dealt with is *sui generis*.

Mr. Siemens.

Mr. ALEXANDER SIEMENS: Before the discussion in connection with the German visit is concluded I wish to say that I think we have been remiss in one respect. The party that went to Germany did not go alone, but many of us had our better halves with us, so I think we ought to put on record that our best thanks are due to the German ladies who took our ladies about and showed them the sights of the towns while we were studying to our hearts' content electrical methods. I think we ought also put on record that the best thanks of the party are due to Mr. and Mrs. McMillan, who did all the hard work of arranging the tour.

The vote was carried by acclamation.

The President.

The PRESIDENT: I have now to ask you to pass a very hearty vote of thanks to the committees, to those gentlemen who have acted as reporters, and to their collaborators who so kindly aided them in collecting the needful data. We have had a most interesting evening, and the subjects dealt with have led to a most interesting discussion. It is but right I should say that the Council have already recorded and remitted resolutions conveying the thanks of the Institution to the principals of the various institutions and establishments who were

so good as to extend to the members of the Institution their hospitality on the occasion of the visit of the members to Germany. I hope it will be understood that we feel very grateful indeed to them for the kindly consideration they bestowed upon us. Nothing could have been more hearty than the welcome extended or more generous than the manner in which they threw open their works for our inspection. The President.

I ask you to testify in the usual manner your appreciation of the reports which have been before you.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

As Members:

Charles Sidney Vesey Brown.
Samuel Wells Cuttriss.
Duncan Macdonald.

As Associate Members:

Walter Henry Alabaster.
Claud Carew-Gibson.
John Leopold Cateaux.
Harry F. Clayton.
Richard Charles Cliff.
James S. Colquhoun.
Charles Day.
George Edwards.
John Edward Ellis.
Arthur H. C. Gibson.
Frederick Golding.
Gerard H. J. Hooghwinkel.
William Inglis.
Adrian Denman Jones.
Arthur Francis Lord.
Thomas McEwan.
William McLellan.
Rudolph Henrik Paus.
Ferdinand George Poulton.
Egerton Goolden Pulford.
Louis Rottenburg.
Egerton Sayer.
James Edmund Sayers.
William Angus Scott.
James Henry Seccombe.
Wilfred Shaw.
Percy George Timms.
Herbert Williams Umney.
David Wilson.
Harry Egerton Wimperis.
Albert Ernest Woodhouse.

As Associates:

Ernest Albert Aston.
Frank Beckett.
Ernest F. Blatchford.
Ernest Austin Brandon.
James Brash.
Harold F. Buttenshaw.
Thomas Carter.
Frank J. Chapple.
Thomas Clark.
Charles Richard S. Davis.
Frederick A. Fitzpayne.
George Edward Francis.
Charles C. Garrard.
Albert Daniel Greatorex.
Wm. Herbert Isherwood.
Ernest A. Livet.
Charles A. McCalla.
Frank McFarlane.
C. R. Montgomery.
William Morrison.
John A. Ornstien.
Robert Orsettich.
Robert M. Powell.
Thomas F. Purves.
Wm. James S. Pyper.
James Quick.
George Scott.
John Senior.
E. James Stockwell.
Wilford H. Taylor.
Nicholas R. Temperley.
James Reid Young.

As Students:

Gordon D. Adam.
Percy Barnes.
Arthur Patrick Boden.
Walter Carter Booth.
C. L. J. Bonnetaud-Nadaud.
Benjamin A. M. Boyce.
Frederick Fermor Brand.
James D. Butcher.
John N. Butler.
Eric Thomas Caparn.
Harry Church.
James Coghlan.
Percy M. Crampton.
Chas. Wilson Crosbie.
Hubert Dann.
Thomas S. Dick.
Harry Alexander Edger.
Edgar L. Elkins.
Harold W. Everitt.
Sidney F. W. Finnis.
Frederick George Fish.
Andrew Howard Gordon.
Ronald Chas. Cecil Green.
Cyril Grimes.
R. L. Higgins.
Geoffrey C. Hollis.
James Hooley.
Alexander Dean James.
Bernard G. Jones.
Douglas Neill Keith.
James Dillon Kelly.
Alfred G. Kemsley.
Joseph Landstein.
Hedley Large.
Harry Welch Lee.
Lucien A. Lewis.
Reginald G. Lewis.
George E. Marley.
Richard B. Matthews.
A. C. M. Maynard.
Harry B. Mitchell.
Dorrien Graham Moon.
William F. Mylan.
Robert S. Newton.
Wm. Edward Ostler.
David Sydney Paxton.
Maurice James Penford.
Edward Billson Percival.
Joseph Jackson Rider.
Reginald G. Roberts.
Harry Rust.
Percy R. Stevenson.
Wm. Gregory Terry.
Hugh C. Thornton.
Henry James Troughton.
James Alfred Troughton.
Chas. Joseph Tyler.
Samuel Utting.
Arthur John Venables.
Walter Maitland Wilcox.
Henry Wilkinson.
Alexander Stephen Wilson.
Wm. James Wiltshire.
Harold Woolfenden.

The Three Hundred and Seventy-First Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 23rd, 1902—Mr. WILLIAM E. LANGDON, President, in the Chair.

The Minutes of the Ordinary General Meeting held on January 9th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—
William Corin.
Henry Robert Low.

From the class of Associates to that of Members—
Gustav H. C. Risch.

From the class of Associates to that of Associate Members—

Louis Emile Aulagnier.	Arthur Henry Pook.
Walter Francis Daniell.	James Henry Millen.
A. Higgins.	E. J. Sander.

Herbert W. Watts.

From the class of Students to that of Associates—

John Alexander Armstrong.	Charles Bernhard Monson.
Henry Richard Carson.	John Guy Pointon.
Francis Medforth Denton.	William G. Shee.
John T. Haynes.	Maurice Solomon.
Charles William Hill.	Reginald N. Torpy.
T. C. Hunt.	William Allen Turquand.
Arthur Priestley Hutchinson.	Theodore Henrich Watermeyer.
Clifford Lakin-Smith.	John Henry West.

Messrs. C. O. Grimshaw and W. Henderson were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Alabaster, Gatehouse & Co., Messrs. Macmillan, and Mr. B. H. Morgan ; to the *Building Fund* from Messrs. H. O. F. Bindemann, J. B. Braithwaite, W. J. Cooper, P. F. Crinks, A. Curtis-Hayward, C. F. Farlow, S. Z. de Ferranti, S. Grant, C. W. Hacking, Captain Jackson, R.N., W. E. Langdon, E. M. Malek, T. Mills, C. Poulsen, L. C. B. Trimnell, and A. D. Williamson; and to the *Benevolent Fund* from Messrs. F. G. Fish, Killingworth

Hedges, J. A. Ornstien, and W. J. S. Pyper, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have much pleasure in reading to you a telegram received from the American Institution of Electrical Engineers:—

(Copy.)

"McMILLAN, Secretary, Institution of Electrical Engineers, London.

"The American Institute of Electrical Engineers, on the occasion of their Annual Dinner, with Senor Marconi as their Guest of Honour, send to their Sister Society their compliments and fraternal greetings.—(Signed) CHARLES P. STEINMETZ, President."

I need hardly say that that telegram is under acknowledgment in the usual manner with the Institution's thanks for their kindly greeting.

I have now to announce that the Council have awarded premiums to the following students for reports rendered at the suggestion of the Council on exhibits at the Glasgow Exhibition. The object on the part of the Council was to induce students to concentrate their attention upon the various exhibits there, and then to devote themselves to a report on the special subjects which had been selected by the Council:—Messrs. A. F. T. Atchison, T. A. Davies, J. D. Griffin, J. B. Langford, P. Laubach, H. L. Percy, A. Raworth, D. Reid, F. E. Robinson, and James C. Smail.

I have further to announce that the Institution, with a view of economising expenditure on the part of those who may require to communicate with the Secretary, have registered as the telegraphic address of the Institution "Voltampere, London," "Voltampere" being one word.

The following paper was read:—

EARTH CURRENTS DERIVED FROM DISTRIBUTING SYSTEMS.

By E. BASIL WEDMORE, Associate Member.

Particular interest has recently been aroused in connection with the subject of earth currents, principally owing to the consideration which has been given to the question of the protection of observatories and other places from magnetic disturbances due to the use of the earth as a return conductor in traction work. Although some of the questions raised have been of only temporary interest, yet as it is certain that wherever there are electrical distribution systems there will be earth currents, the consideration of the earth as a conductor and of the phenomena accompanying earth currents is a subject of permanent interest.

My connection with the practical side of the subject has been hardly more than sufficient to enable me to see how many problems there are yet unsolved, but it has been thought that a general statement of some of the conclusions arrived at, accompanied by a demonstration of their application to the explanation of certain well-known facts, would serve to open the subject for discussion, when undoubtedly a quantity of useful data and opinions will be forthcoming.

As the theoretical part of this subject has been built up in connection with the question of magnetic effects, the matter will be most easily approached from that point of view.

I am indebted to Mr. Trotter, with whom I was experimenting in March, 1900, for drawing my attention to certain early work of Heaviside's written at a time when earth return currents were, to say the least, not likely to do away with gas- and water-pipes, and which forms the basis of the following considerations. The principal conclusions with reference to the magnetic effects were arrived at before April, 1900, but I was prevented at the time from publishing them, principally by illness, except among interested parties.

We shall commence by considering the current distribution accompanying the use of the earth as a return in a simple traction system, and we shall approach the subject from the magnetic side. On first consideration it might appear that the magnetic effects at any point away from the rails would be produced principally by the currents in the immediate neighbourhood of that point, but this is not the case, for the magnetic forces due to the long distant streams of current are roughly only inversely proportional to their distance, so that the large current flux passing through the enormous areas below the track will have a relatively large effect as compared with that due to the small current flux in the immediate neighbourhood. In determining the magnetic effects at any point it is necessary, therefore, to consider the magnetic effect due to the current system as a whole.

Should the whole current return by the rails the magnetic effects due to the current in the trolley wires and rails would practically cancel, except in the immediate neighbourhood. A large proportion of the current,

however, returns by the earth, and at a distance from the trolley wire. The magnetic effects due to the current in the trolley wire, therefore, are not cancelled by the return currents. In this sense it is correct to say that the magnetic effects are due to the earth currents.

When the engineer, familiar with electric circuits, turns his attention to problems connected with magnetic circuits, he is assisted by finding relations between magneto-motive force, magnetic flux, and reluctance, similar to those between E. M. F. current and resistance. When he meets with problems involving the distribution of current fluxes in space instead of in linear conductors, he will be assisted by his familiarity with the distribution of magnetic fluxes under similar conditions. There is perhaps something more than an analogy here between the electric and the magnetic flux, and may be it is only due to the limitations of our present state that we do not recognise it. The two fluxes are always linked together in closed circuits, and there is a definite quantitative relation between them. The difference in permeability between the most permeable and the least permeable substance is something of the order of 3,000. The difference in conductivity between the best conductor and the best insulator is, of course, of a higher order altogether. It is practicable, therefore, to carry current fluxes through very long conductors of small section without appreciable loss, while this cannot be done with magnetic fluxes. Perchance some would-be pioneer has already applied for a patent for transforming up magneto-motive force, and it is only the difficulty of obtaining the necessary magnetic insulation between the turns in his magnetic circuit that will give him trouble. Two turns might be practicable.

We are familiar with the calculation of magneto-motive force in a closed magnetic circuit, from the current flux passing through that circuit, from the relation :—

$$4\pi \times \text{current flux} = \text{magneto-motive force or line integral of magnetic force.}$$

We know also that we cannot produce M. M. F. in the circuit by means of currents which do not link with the circuit. From this it follows that, given the M. M. F. in a closed circuit, we can calculate the current which passes

through, and is linked with, that circuit. In general, in any magnetic system produced by a corresponding current system, we may calculate the current passing through any closed curve by taking the line integral of magnetic force round that curve and dividing by 4π.

The first practical deduction to be made from these considerations is, that at any point where the magnetic flux is relatively weak the current must also be relatively weak.

On the assumption that the specific conductivity of the earth is uniform and that the return currents enter and leave at points, it may be shown that the magnetic force directly due to the earth currents has no vertical component. If this is so, then no part of the vertical component due to the current in the trolley wires and feeders is cancelled by the earth currents. We may see, also, that except close to the line the magnetic field due to the current in the trolley wire will have no horizontal component. In the hypothetical case, therefore, the horizontal component is wholly due to the earth currents and the vertical component to that portion of the trolley and feeder currents that is not cancelled by the rail return current. We know that in the immediate neighbourhood of the track the trolley current will have a considerable horizontal component. Half a mile out, however, this component will be quite negligible and the general statement holds good.

Should the assumptions made not be representative of the real conditions, then in the real case some portion of the vertical component will be cancelled and the magnetic field reduced. The only exception to this would occur in case there were a large conducting system lying in and parallel with the current stream and having good electrical connection with the earth.

As the above allocation of the horizontal and vertical components of the magnetic forces is of considerable importance, some amount of explanation is desirable. Take the simplest hypothetical case (Fig. 1), in which a certain current flows from A to B in an insulated conductor lying on the earth's surface and returns by the earth, entering the earth at the point B and leaving it at the point A. The magnetic field due to the current in the insulated conductor will be a circular one, the lines of force entering and

leaving the earth's surface at right angles, so that at the surface there is no horizontal component.

Consider now the current flux entering the earth at the point B. The current will tend to spread out uniformly in all directions, its density decreasing with the square of the distance and the potential varying inversely as the distance. The current flux distributes in a medium of uniform conductivity as a magnetic flux would distribute in a medium of uniform permeability, and we may calculate the resultant distribution of a current entering at one point and leaving at another just as we should calculate the resultant magnetic flux due to a north pole at the first point and a south pole at the second. The current at any point will be in direction and strength the resultant of the incoming and outgoing currents there would be at that point were there only an incoming or outgoing current flux.

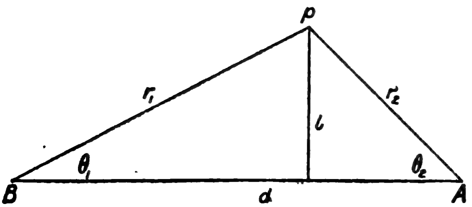


FIG. 1.

Now the magnetic field due to a current entering the earth's surface at B and diverging uniformly will obviously be symmetrical about a vertical axis. It will have equal strength at equal radii at points on the earth's surface and in planes parallel to it. Whatever the distribution may be, we know that the line integral of the magnetic force round any closed curve $\div 4\pi$ will give us the current passing through that curve. We are most interested in the force at the earth's surface. Assume for the moment that the current arrives at B along a straight vertical wire, then any closed curve on the earth's surface including the point B will include the whole current. We have now found two conditions, namely:—

(*a*) Uniform, and therefore circular, distribution of the magnetic field, the circles having circumferences of $2\pi r$.

(*b*) Line integrals round these circles to be all equal and to have value $4\pi c$.

The field strength, therefore, at any point, will equal $\frac{2c}{r}$.

The field at the surface, however, due to the long wire bringing up the current to the point B will $= \frac{c_1}{r}$ therefore the field around B, due to the diverging current flux, which is what we require, will also equal $\frac{c}{r}$. It is obvious from symmetry that there can be no vertical component.

We may now resolve our forces due to the systems at A and B. For the horizontal component, if B is distant d from A, then the force at any point p distant r_1 and r_2 respectively from B and A $= \frac{c\,d}{r_1\,r_2}$ in absolute units.

If the current is fed along a wire from A to B, the vertical component at $p = \frac{c}{l}(\cos\theta_1 + \cos\theta_2)$ where $l =$ perpendicular distance of p from the wire and θ_1 and θ_2 are the angles between the wire and r_1 and r_2 respectively.

It has already been shown that current passing along the trolley line and feeders and returning by the rails has no appreciable magnetic effect except in the immediate neighbourhood of the track. For the purposes of calculation, therefore, we neglect this portion of the current. For the purpose of a first approximation we may guess at two points, A and B, at which the current may be supposed to enter and leave the earth, and apply the above formulæ.

Mr. E. Parry has shown, in a contribution to the *Electrician* for August, 1900, that on the assumption that the principal resistance offered to a current entering or leaving the track is in the immediate neighbourhood of the track, that the track is uniformly grounded, and that all the current enters the rail at one end and leaves it at the other, the amount of current leaving the track from point to point follows an equation of the same form as Fourier's equation for the heat flux radiating from a long conductor heated at one end. Professor Rucker who arrived independently at this result and also at the source and sink theory above described, has given a mathematical treatment of the subject in a contribution to the Physical Society, which appears in the *Philosophical Magazine* for April, 1901. Professor Rucker shows how to calculate the vertical magnetic effects on the assumption of the Fourier bar theory and source and

sink theory combined, and Dr. Glazebrook has worked out some examples and deductions from the same.

Fortunately, or unfortunately, the hypothetical cases rarely fit the real cases, and I find an intelligent use of the simple formulæ given above leads to quite as accurate results as the use of the more complex formulæ alluded to.

Before making practical application of these conclusions there is another fundamental question which requires to be dealt with. Doubt has been thrown on the truth of the fundamental assumption of the source and sink theory. It has been suggested that while the experience of traction engineers goes to show that the earth is a very reliable quantity—that for instance the proportion of the total current which leaves six miles of line is nearly independent of the situation of that line—yet, the earth may not be a homogeneous conductor. Dr. J. Edler has suggested that the return currents are carried by a layer of damp ground extending only a small depth below the surface, having founded this theory on the results of experiments performed near the electric tramway of Spandau.

Now a little consideration will show that the formulæ deduced above for the magnetic effects at the surface of the earth, due to return currents flowing through it as a homogeneous conductor, are equally applicable to the surface conditions due to return currents in a thin layer of earth. The vertical effects due to the outgoing current are obviously unaffected, while the reasoning previously applied to the calculation of the horizontal forces will be found to apply also in this case.

As this is a point of considerable importance, I shall proceed to show that the theory fits the facts.

Professor Rucker has already shown an agreement between theory and experiment based on measurements made at Stockton. I give in the following table (p. 583) the measured disturbances reduced to 100 amperes in the outgoing feeder, the line being two miles long and the observing stations 0·4 and 0·8 mile distant, along a perpendicular from the centre of the line, and side by side I give my calculated values on a first approximation. The unit used = $\frac{1}{100000}$ absolute units.

Observed.				Calculated.			
0·4 Mile.		0·8 Mile.		0·4 Mile.		0·8 Mile.	
V	H	V	H	V	H	V	H
4·5	3·0	1·5	1·5	4·2	2·1	1·7	1·25
4·5	2·3						
3·0	2·3						
3·0	1·5						
4·5							
4·5							

V = Vertical component. H = Horizontal component.

Dr. Edler's experiments covered a much larger area, the most distant observing station being nearly five miles from the track. Figure 2 shows the relative position of the track and of the seven stations at which observations were made. From the observed forces I have calculated the leakage currents. I have assumed that a current flowing through the earth between the points H H would produce

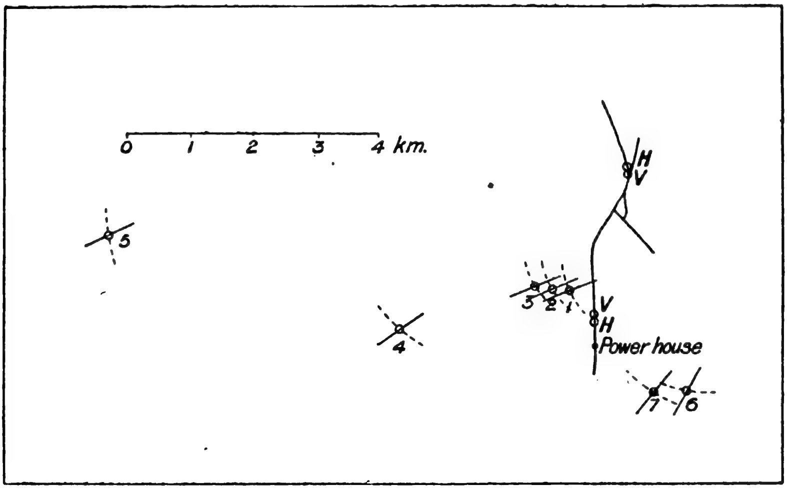


Fig. 2.

about the same horizontal disturbance as the actual current stream, and that a current of uniform strength flowing in the trolley wire between the points V V would produce about the same vertical disturbance. The following are the results obtained :—

Station.	Observed Disturbance.		Leakage Current Calculated from Observed Disturbance.	
No.	V	H	From H	From V
1	25·2	9·5	53 amps.	64 amps.
2	10·6	6·1	47 ,,	57½ ,,
3	4·3	4·3	46½ ,,	42 ,,
4	0·95	1·3	77 ,,	66 ,,
5	0·24	0·44	113 ,,	59½ ,,
6	1·00	1·4	58½ ,,	37 ,,
7	1·10	1·7	52 ,,	36½ ,,

Although at first sight this may not seem a striking confirmation, an examination of the figures in the two right-hand columns, together with the diagram, reveals several interesting features.

(1) Except at the first two stations the vertical force appears to have been proportionately less than the horizontal, showing that some portion of the vertical force has been cancelled by irregularities in the current streams. (The line bends outwards towards the first two stations, which being the nearest are most affected thereby, thus accounting for the apparent discrepancy.)

(2) The current fed along the part of the line below the power-house is reversed in direction, thus accounting for the apparent reduction of the vertical effects at stations 6 and 7, without affecting the horizontal disturbance.

(3) Considering the above the vertical effects are far more uniform than the horizontal, which would be expected from the uniformity of distribution of the line current as compared with the earth currents.

(4) It may be noted that, excepting station 5, at any particular station there is a good agreement between the currents calculated from the two disturbances. The differences between station and station being undoubtedly due to variations in the load from day to day, the experiments having been made on different days at different stations. At station 5 the whole calculation turns on the measurement of a few millionths of a line of force per square centimetre.

Taking the figures as a whole we may estimate the

leakage current as about 60 amperes—not an unlikely value considering the length of the line and the service 15-motor and 2-trailler cars.

The agreement between the observed and calculated values given by Dr. Edler is, in the case of the horizontal disturbances only, closer than that just shown. The formulæ used, however, appear empirical, and the closeness of agreement more unfortunate than otherwise, as Dr. Edler was probably misled into accepting the theory, as was the writer at first, by the agreement obtained. Dr. Edler makes no attempt to calculate absolute values or to show agreement between the relative values of the horizontal and vertical disturbances.

The direction of the observed horizontal disturbances is indicated in Figure 2. In the case of a current sheet these disturbances should be normal to the current stream lines. These lines should be circles passing through the points H H. The dotted lines in the figure are portions of such circles, and it will be seen that they are approximately normal to the magnetic lines.

The direction of the current lines would not be very different were the earth a solid conductor. In Figure 3 are shown the current streams for a sheet, the current entering at B and leaving at A. Figure 4 illustrates an approximation to the current distribution that would obtain in a hypothetical case in which all the current is fed into one end of the rail and taken out at the other, the leakage being distributed as in a Fourier bar. Figure 5 gives the surface distribution of current streams on the assumption of a homogeneous earth, the current being fed in at B and taken out at A. A simple graphical construction for obtaining these curves is given in Figure 6, and is the same as would be used for a magnetic flux.

In the light of the above we are amply justified in concluding that we know the distribution of magnetic force in the neighbourhood of a traction system, and that we know the direction of the current streams near the surface of the earth, but further information is required before we can calculate their strength, for if the current flows in a plane of relatively small thickness the current density at any point will be *inversely as the distance* between the lines of current (see Figure 4) while if the current flow through the body of

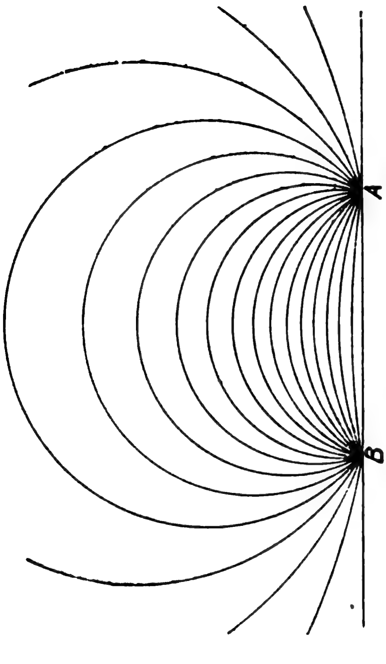


FIG. 3.

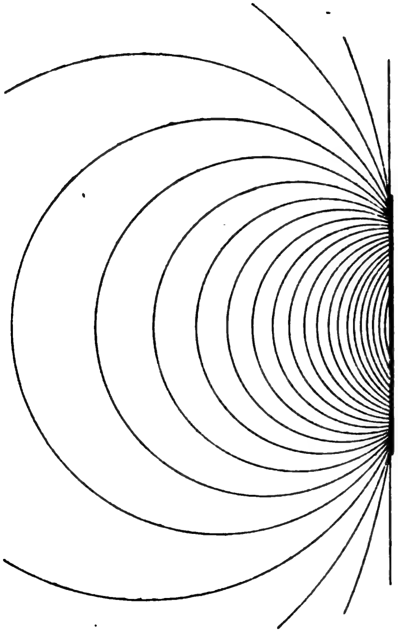


FIG. 4.

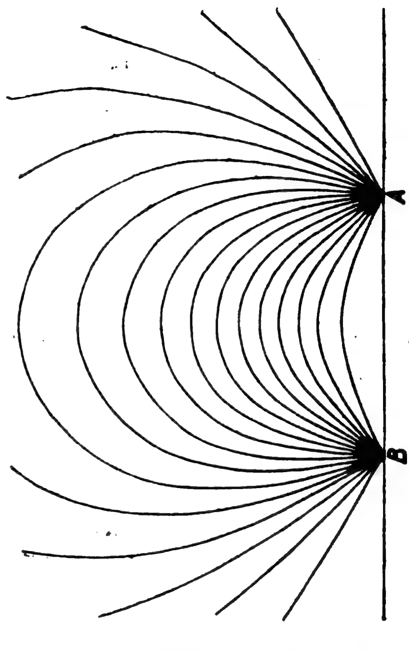


FIG. 5.

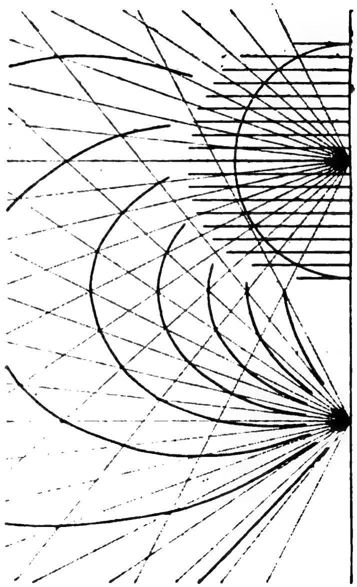


FIG. 6.

the earth the current density at any point will be *inversely as the square of the distance* between the current lines at that point.

At Stockton we have seen that the horizontal component of the magnetic disturbance at a point 0·8 miles from the line was 15×10^{-6} absolute units. If the earth is a solid conductor, the fall of potential along the current stream must have been at the rate of about 1 volt per 60,000 yards. If the current sheet be 250 feet deep, the voltage drop must have been about 1 volt per 1,000 yards. At greater distances from the line the difference between the two results will be largely increased. In calculating these values, the specific resistance of the earth has had to be considered. I shall show shortly how this was arrived at.

Meanwhile, let us continue the examination of the point at issue. When the bonded rails for the track of the London United Tramways Company were laid, it was found by experiments on some 2½ miles of track, that there was a variation of potential occurring along the rail such as would be caused by traction systems, and such as would correspond to a flow of + or − 15 amperes along the rails. The current alternated in direction. The mere fact of the rails collecting such a large current would show that the conductivity of the return path in the neighbourhood was considerably improved by the rails, so that the voltage drop before the rails were introduced must have been still higher. The voltage drop was as high as about 0·2 volt per mile, which, considering the distance of the nearest traction system, points to a current sheet.

Fall of potential tests made at divers places by divers persons give values at least as high as the figure given for a 250-foot current sheet, which makes it probable that often, if not always, the currents return in a sheet of comparatively small depth. In the light of these considerations additional interest will be attached in future to such tests.

Let us now consider the conditions holding in the immediate neighbourhood of the track where the current densities are greatest. In a paper previously alluded to, Mr. Evan Parry has shown that there is an apparent resistance between the rail and the body of the earth of about 740,000 ohms over a square inch. This is equivalent to about 5,000 ohms over a square foot, so that if the rail was at a potential

of 5 volts above that of the earth, the maximum current density would be less than one-thousandth of an ampere per square foot, and this would rapidly decrease as the distance from the rail increases. I have already shown how to estimate the paths of the current streams through the earth. Consider the path of any portion of the current flux. The current leaves the rails, enters the earth, spreads out into a larger and larger stream as it leaves the track, curves round towards the point of return, converges on to a distant part of the rail, and enters the same again. Now on its path it meets with certain resistance offered by its earth path, possibly certain resistance offered at the contacts between rail and earth, and possibly with certain electrolytic E.M.F.'s. We know the total apparent resistance of the whole path. If we assume that the whole of the resistance is that offered by the earth, and with that as basis calculate the specific resistance of the earth, we shall be over-estimating rather than under-estimating the value of the same.

On several occasions since March, 1900, I have approached this question, having estimated as accurately as possible the dimensions throughout of one or more current paths through the earth, based on measurements made in England and Ireland, and again on Mr. Parry's published data. Given the dimensions, the calculation of the specific resistance is easy. The values obtained have always been in the neighbourhood of 75 ohms per yard cube. We may compare this with the values of 50 ohms per yard cube for clay containing about 60 per cent. of moisture and 35 ohms for sand containing about 8½ per cent. given by Herrick.

Dr. Fleming, in an important paper read at the meeting of the British Association, at Bristol, in 1898, gives a value of 17 ohms per yard cube for clay, based on laboratory measurements, and 1 ohm per yard cube for sand wetted with salt water—a figure which is interesting in connection with Mr. Trotter's experiments on voltage-drop near the sea in Cape Colony. Dr. Fleming gives reference to experiments made in 1896 by Dr. St. Lindeck at Berlin, in which the following results were found :—

Cement in normal condition............	50 ohms per yard cube.
Cement after 22 hours soaking in water	15 " "

Cement artificially dried at 100° C.	50 ohms per yard cube.
for $5\frac{1}{4}$ hours	270 " "
Concrete, 1 pt. cement, 5 pts. gravel, minimum value	25 " "
Concrete after drying.....................	500,000 "

We may apply the value of the earth's specific resistance to the estimation of the current that would flow into a pipe of a given diameter, given the potential difference between the pipe and the body of the earth.

Let r_1 = radius of the external circumference of the pipe, in inches.
r_2 = a larger radius measured from the axis of the pipe into the earth, in inches.
K = specific resistance of the earth = 2,700 ohms per inch cube,

then R the apparent resistance of the earth over a square inch of pipe surface is given by the following :—

$$R = 2{\cdot}303\, K r_1 (\log r_2 - \log r_1),$$

from which we may calculate the current density for a given voltage.

If we allow, taking into account the spreading of the current as it leaves the pipe in a direction parallel to the axis of the pipe, that the whole resistance will be practically equal to that reached at a radius of 1,000 inches without spreading, then inserting 2,700 for K, we have :—

$$R = 6{,}000\, r_1 (3 - \log r_1).$$

For a 10-inch pipe we have R = 69,000, while for a 2-inch pipe R = 18,000 ohms, that is to say, the smaller the pipe the less the resistance over a square inch of surface. This is perhaps an unexpected result.

In estimating the value for K it was found that one-fifth of the resistance to the earth currents is encountered in the first 10 feet of ground, and about half in the first 100 feet. The value obtained therefore is not materially affected by any considerations as to whether the currents penetrate below a depth of a few hundred feet or so.

It might be thought that the presence of pipes in the surface layers of the earth would so materially improve the conductivity near the surface that return currents would be

almost confined to that region. Were this the case, however, the conductivity would be largely dependent on the state of the weather. So far as I can discover, all experiments on a large scale have shown the contrary to be the case. I have attempted to discover traces of electrolytic E.M.F.'s by a careful comparison of the theoretical curves given by Mr. Parry with curves obtained in practice, but have been unable to obtain any positive evidence. In general, the agreement and general reliability of the curves in cases where the E.M.F. is both below and above that necessary to decompose water would seem to be additional evidence that the conductivity of the earth did not depend much on electrolytic actions. Experiments made by Mr. George Claude and communicated to the Société des Électriciens in July, 1900, showed that if a current was passed between lead plates buried in the earth with a potential difference of 23 volts, the amount of decomposition produced was as though only 40 per cent. of the current had been flowing, and this figure was reduced to 4 per cent. if the voltage was reduced to 1 volt. Herrick has given a figure corresponding to the latter for iron plates.

Recent observations tend to show that in the past electrolytic troubles have been very much overrated, and that in many cases corrosion not due to earth return currents but to the usual taxes levied by Nature from the users of inferior metal, have been attributed to the return current. Cast iron has been found more free from corrosion than wrought iron, and oxides produced at the seat of electrolysis increase the resistance, and reduce the electrolytic current.

It is quite a different matter when one comes to consider the effects due to leakage in connection with the earthed middle wire of a three-wire lighting system. In this connection the formulæ developed above for the current density in the surface of small pipes will be found of interest. To those who are not accustomed to figuring the insulation resistance of thick dielectrics on thin wires, some of the deductions which may be made from the formulæ referred to may prove curious. For instance, in the limit where the wire is very small it will be seen that the current density is inversely proportional to the radius of the wire. Now the current density is a measure of the rate of change

of potential through the dielectric. For a given E.M.F. we may increase the dielectric strain up to any limit we please, even above the breaking limit, if only we make the wire small enough.

The notion that there is a practically constant resistance between tram rails and the body of the earth, now well proven, serves to simplify the consideration of many problems depending on the nature of the earth return. As an example a brief consideration will be given to the question of bonding water-pipes to the rail in the neighbourhood of the Traction Station—a question on which some difference of opinion has recently arisen in at least one quarter.

The primary object is to reduce both the *area* of pipe *out* of which current is flowing, and to reduce the *density* of the outward flowing current. If there is no connection between the pipes and the rail, the current flowing into the surface of the pipes must equal the current flowing out of the surface of the pipes, and when either is a minimum both will be a minimum. The rail being disconnected from the pipes, its potential will be such that the sum of the resistances to the inward and outward flowing currents will be a minimum. A point about the middle of the rail will be at zero potential, the further end + and the station end –. The earth current will also be a minimum. If now the + or further end of the rail be connected to the pipes, the area over which the current leaves the pipes will be considerably augmented, but the area of rail – to the earth will also be considerably augmented, thus increasing the total leakage current. If, however, the – end of the rail be connected to the pipes, the rail as a whole will be positive to the earth and the pipes as a whole will be negative to the earth, the amount of current leaving the pipe surfaces being a minimum. The pipes may now be considered as an extension of the rail, and the best protection will be obtained when the point of junction is at the earth's potential, other things being equal. The currents entering and leaving the pipes must be equal, *but no current now leaves the pipe surface.*

We have now, however, very largely increased the currents carried by the pipes. While this may be to the advantage of the current user, it may not be so to the pipe owner. At each bad joint the current will leave the pipe over

a limited area at a high density and return again further on. The smaller the pipe, the higher the current density. If, moreover, the pipes are conveying electrolysable liquids internal as well as external damage may ensue.

If one had it in one's power to lay both pipes and track in the best possible manner, it would seem best where metal pipes are used to use cast iron, to introduce resistance at every joint, to introduce any possible surface resistance, and to avoid all connections with the rails, leaving the rails to take their own potential.

In conclusion, may I express the hope that this paper will serve at least to draw attention to the lack of information on this important subject, and that in the discussion that follows, will be found the key for future investigations?

The Chairman.

The CHAIRMAN: Dr. Glazebrook was to have favoured us with his presence here to-night. The subject with which Mr. Wedmore has dealt is one in which he has taken the greatest interest, but I am sorry to say he is prevented from being here. He has, however, sent a communication. It is exceptional, I know, to read communications of this kind at the meetings, but in this instance I will ask you to allow the communication to be read, because I am sure it will prove interesting.

The following communication from Dr. Glazebrook was read by the Secretary :—

Mr. Glazebrook.

Mr. R. T. GLAZEBROOK (*communicated*): Mr. Wedmore has referred to papers on the same subject published in the *Philosophical Magazine* for last April by Prof. Rücker and myself. Prof. Rücker developed his theory, as Mr. Wedmore points out, on the assumption that the track is uniformly grounded, and that leakage, according to Fourier's law, goes on along its length. I stated in my paper, however, that the application of this to practical problems is "somewhat complex," and that it suffices to suppose that all the leakage current leaves the track at the car and returns to it at the power-station. Thus Prof. Rücker's equations are simplified, and those which I used, pp. 433 and 441, are identical with the equations, developed by Mr. Wedmore. For c the leak-current, I have used the symbols Ik, I being the current in the trolley wire, and k a leakage coefficient which, as Mr. Parry showed, depends on the length of the line and on the conductivities involved, while my two fractions $(a + b)/r_2$ and b/r_1 are the $\cos\theta_2$ and $\cos\theta_1$ of Mr. Wedmore's expression.

It may be of interest also to repeat a table from my papers giving the comparison between Dr. Edler's experiments and the simple theory in a rather different form from that in which it is given by Mr. Wedmore. The table gives the values of the calculated and observed vertical disturbing force, and is based on the assumption that in the line in question, about three miles long, the proportion of leakage current to current in the trolley wire is 25 per cent.

Mr. Glazebrook.

TABLE.

Distance from line in kilometres.	Vertical Disturbing Force.	
	Calculated.	Observed.
0·38	12·8	23·17*
0·64	7·3	10·6
0·79	5·8	5·6
0·92	4·9	4·3
3·01	·99	·95
7·48	·21	·24
1·54	1·5	1·04

The amount of leakage assumed is rather in excess of Mr. Parry's number for a line three miles long, but agrees fairly with some other experiments. It will be noted that at the two shortest distances the calculated disturbance falls greatly short of the observed. This probably might have been anticipated; the distances about half a kilometre are too small to allow the approximate theory to be considered trustworthy. Then from 0·79 to 7·48 kilometres the agreement is excellent. In the case of the last observation at a distance of 1·54 kilometres, the river Havel passed between the line and the observing station. Since the theory assumes earth of uniform conductivity, it clearly ought not to be pressed too far in this case, and a discrepancy was to be expected.

The agreement between the theory and the observations is much less good in the case of the horizontal disturbance.

Mr. EVAN PARRY: Mr. Wedmore has referred to my paper on the subject of stray current from track rails when forming part of the circuit of an electrical tramway. I would like to state briefly that the treatment of the subject was based upon the evident analogy between a rail when subject to a difference of potential between any two points, and a bar when heated at one point and cooled at another, the conductor in such case being surrounded by a medium of lower conductivity. Mr. Parry

This theory was called upon to account for a great number of facts which had accumulated in the course of several years. The main facts as they presented themselves to me were, first, the exponential character of the potential and current curves along the rail; secondly, it was found that the leakage was independent of the weather conditions, a result contrary to a preconceived notion on the subject. In the third

* This corresponds to the 25·2 of Mr. Wedmore's paper, but in my copy of Dr. Edler's note the figure is 23 not 25.

Mr. Parry. place it was found that the leakage was independent of the locality, a result which one might reasonably expect having regard to the uniformity of the track constructed in this country; and in the next place it was found that the proximity of metal pipes in the earth has no particular influence upon the total amount of stray-current, provided, of course, that they are not metallically connected to the rails.

These facts, considered in conjunction with Fourier's theory already alluded to, led to the further conclusion that the stray currents did not confine themselves to comparatively highly conducting channels, either pipes, or strata or streams, but were diffused throughout the mass of earth generally, for the same reason that diffusion takes place between rail and earth; and although the earth is not homogeneous in its electrical properties any more than in its physical properties, and different layers and every particle in those layers will be found to vary in their conducting properties, in consequence of which the lines of flow cannot be uniform, still I think for all practical purposes connected with the influence of stray currents upon observatories, etc., the earth may be treated as a solid homogeneous conductor.

Dr. Edler has explained certain facts on the assumption that stray currents are confined to a highly conducting surface layer, and I am glad to note from Mr. Wedmore's paper that the facts can be explained equally well on the assumption that lines of flow radiate and spread out in all directions. Dr. Edler's theory seems to me to be untenable, because if we assume a surface layer of comparatively high conductivity, with a surface of demarcation between it and a second layer, and compare the relations between these two layers with that existing between the track and surface layer, in the first place the surfaces are much larger and much more intimate, and in the second place the difference in conductivity between the two layers is of a very small order indeed compared with the difference between the track and the first layer. Now if leakage takes place between the track and first layer to the extent and degree which we all anticipate, and of which we find an example in Mr. Wedmore's paper, much more will it diffuse itself between the first layer and second layer. The same reasoning applied to each successive layer will bring us back to the general diffusion theory, which I have stated to be equivalent to the homogeneous earth theory for certain purposes. The same line of reasoning will help to explain why large masses of metal pipes are of so little importance in the conductance of the earth as a whole. What actually takes place can best be realised by the use of the heat analogy. A line of pipes placed in a field of stray currents will act in precisely the same way as if placed in a medium with a temperature gradient such as the main flue of a generating station. The quantity of heat conducted across a section of the pipe at any point will depend upon its internal conductivity for heat and the conductivity between its surface and the surrounding medium. In the same way a pipe in a stray field will take its proportion of current depending on the corresponding electrical properties, but will not affect the amount of leakage from the rail, provided of course it is not connected to the rail.

Reference has been made as to the meaning of earth potential. As

we are only concerned with relative potentials of, let us say, the track and the earth, I have always regarded that part of the track to be at earth potential at which currents cease to flow out and begin to flow back again. Mr. Parry.

With regard to the measurement of stray currents, there are two ways, equally simple, of doing this; one is to measure the current actually in the rail at different points by means of a potentiometer, the other is to connect the potential wire at different points on the track and so obtain the curve of potential along the track; the current at any point can then be deduced from the potential gradient at that point.

I think we are much indebted to Mr. Wedmore for his paper. Its value consists in the simple relation which he has established between the amount of stray current and the forces acting on a magnetometer. On the whole, I think the tests to which he has subjected his theory are fairly conclusive.

Mr. A. P. TROTTER: After the vortex of controversy into which some persons were unwillingly drawn some months ago, it is very pleasant to discuss this subject in a calm scientific manner, with or without mathematics. The paper contains many problems; some are of fascinating interest, and others of very considerable commercial importance. I think that those who have not studied the matter before will hardly be convinced by the very brief manner in which the author has brought forward the source and sink theory; I accepted the theory at first, on authority, because it was held by those who had studied it more deeply than I. It is not the earth currents themselves which produce the vertical disturbances in magnetic laboratories, but the unbalanced current in the trolley wire—the difference between the total current in the trolley wire and the current returning by the rails, so that the earth currents only by their inactivity produce these disturbances. The author alludes to the interesting question of a conducting system lying in a current stream. This problem is still, I think, in a very immature state. It was asserted that when 2½ miles of tram were laid down in Middlesex, there apparently were 15 amperes flowing up and down in the rails. These were measured by potential differences. I should very much like to see that experiment repeated again, because it was imagined that these were leakage currents from existing lines—say the Central London Railway—which were concentrated into these paths of low resistance. The normal earth currents known to telegraph men, but measured by them over scores and hundreds of miles, attain very considerable values. I do not know that any one has carried out very careful measurements of the normal earth currents over one hundred yards. I have carried out dozens of such experiments, but I do not call them very careful ones, because a great deal of care is necessary to eliminate small polarising and accidental effects. The author has spoken of one volt per thousand yards. I have found differences of about that value, that is to say $\frac{1}{10}$ of a volt per one hundred yards, miles away from any tramway, changing the electrodes to eliminate local action. They could only measure the earth volts—the difference of potential; they could not catch hold of the amperes. It may be that these currents flowing through the earth may be Mr. Trotter.

Mr. Trotter. grouped and gathered together into a low resistance conductor, so that to lay down a tramway is to short-circuit a county. Mr. Glazebrook has shown that strong currents, if thus concentrated, would not act differently to equivalent diffused stray currents.

I have a mass of undigested facts about stray currents which is the result of a good many experiments I made in the neighbourhood of Cape Town with Mr. B. Bayly. Mr. H. D. Wilkinson worked a good deal with me in the latter part of those experiments, and he, too, has a good deal of information, which I hope he will some day publish. I found that driving two steel rods a yard long into the ground, sometimes near the tramway—as I mentioned in my paper on Cable Disturbances—currents were to be found, and were assumed to be tramway when the galvanometer needle was seen working corresponding to the motion of the tramcars. We judged they were normal earth currents when the needle was perfectly steady. The soil being rather dry, the emptying of a bucket of water in the neighbourhood of the electrode completely upset the direction of the current. On the other hand, on going to the other end and emptying two buckets the direction was altered again, so that the cônditions are very sensitive, and very small differences of conductivity will evidently alter these currents. These currents of which I am speaking are measured over small distances, and therefore you may imagine that the lines of current-flow were straight, whereas the earth currents observed by telegraphic people may be sinuous and curve about over a large area of ground. The subject can be treated mathematically, and most interesting results can be obtained; but Nature, quite familiar with the behaviour of hot bars, does not, Herself, expand Fourier series, or evaluate Fourier integrals. No doubt these things will become less repulsive and more intelligible when they are explained geometrically. Mathematical complications are the result of the poverty of mathematical language.

Coming to the practical conclusions at the end of the paper, I am not quite prepared to agree with the author's views about the deliberate connection of water or gas pipes to tramway rails. He says that "the best protection will be obtained when the point of junction is at the earth's potential, other things being equal." But it is not easy to discover what the undisturbed potential of the earth is. Of course, with the huge stray currents from American tramways it is a different matter, but with the moderate currents which are to be found in pipes in this country it appears that the currents which enter the pipes where the pipes are negative to the rails had better be let out through a metallic path. M. Claude says that if you make the connection you will increase those currents seriously. I should like to see what the result is. I have asked many tramway engineers to try, and I now ask again those who have an opportunity of doing it to put the matter to test. For instance, take a pipe, measure the current in it by the method described by M. Claude—by taking the difference of potential between two points on the pipe, then shunt those two points by an ammeter, read the current shunted and the new potential difference, and calculate the original unshunted current. It is extremely simple. Now make a connection to the most negative point on the system, at the works

or where your return feeder is connected to the rails, and see if the current is seriously increased. I do not believe that with English conditions it will be so seriously increased as to give rise to the trouble to which Mr. Wedmore alludes, namely, what is called the joint-jumping electrolysis. I believe that will only occur under American conditions. Again, Mr. Wedmore talks of pipes containing electrolysable liquids. It has been suggested that a water-pipe is a more serious matter than a gas-pipe because there is water inside. In Mr. Crompton's laboratory there is, or used to be, a handy megohm, consisting of thirty feet of three-quarter inch garden hose full of tap water. I do not think that the water in a thirty-inch main would increase the current by one-millionth part. Mr. Trotter.

I would now like to go back to the beginning of the paper, where Mr. Wedmore speaks of certain experiments in which he has been engaged. I was very much interested in the subject of earth currents in connection with magnetic observatories, and not being able to calculate how they would be likely to go, I carried out some experiments, following precisely the mode adopted by Professor Grylls Adams in a paper reprinted in Mr. J. E. H. Gordon's book on Electricity and Magnetism. There Prof. Adams shows how to draw equipotential lines by putting a current into a sheet of tinfoil and exploring with wires from a galvanometer. I took a sheet of tin, and soldered twenty pieces of wire along the edge at inch intervals, each wire about a yard long. I put an ampere into each—that is to say, 20 amperes in all. The wires were made of considerable length in order that the potential at the ends might be practically the same. At one point, or at various points, according to the experiments I was making, I took the current out. I used an ordinary Weston instrument, with no resistance added, and explored. I got a certain deflection. I then moved the electrode along, keeping the deflection the same, following it with a pen and drawing the curve on the sheet of tin. It was one of the most fascinating experiments I have ever tried. I was too busy to carry it out thoroughly, and I was very much indebted to the assistance of Mr. Wedmore, who continued the work and made a number of these experiments in my laboratory until, unfortunately, he was stopped by illness. The potential lines were found by experiment and interpolation, and the lines of current flow, which are always to be at right angles to the potential lines, were drawn afterwards by eye. Not having heard of the source and sink theory at that time, I thought that these lines might be so arranged as to get a place devoid of current, which would form a nice site for building a magnetic laboratory. I was quite wrong in the idea so far as vertical force is concerned.

Having obtained a number of diagrams, I went a step further and made some models; in plan they correspond with the diagrams, the height represents difference of potential. To carry out the analogy, we may imagine a sheet of drops of water falling down on to the line A B of the diagrams (pp. 598, 599).

The dotted lines show the direction in which the drops would run, always going downhill, and finally converging to the sink. Not until after the models were made did I notice how the undisturbed potential

Mr. Trotter.

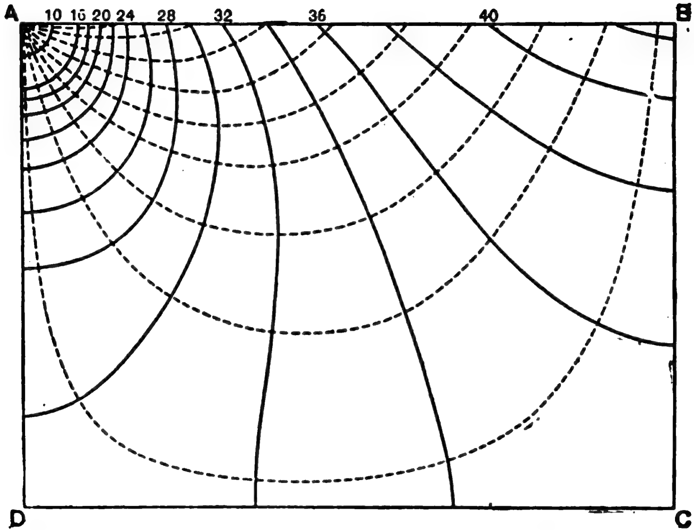


FIG. A.—A B is the line into which the current is fed at twenty equidistant points. A is the point at which all the current leaves the sheet. The full lines are equipotential lines, found by experiment; the dotted lines are lines of current flow, deduced from the former. Owing to the limited size of the sheet, the lines are distorted near the edges B C and C D. The figures represent differences of potential.

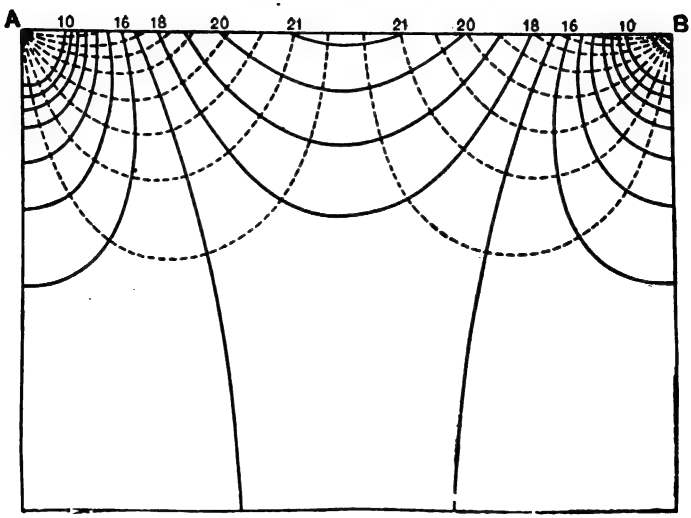


FIG. B.—A B is the line into which the current is fed. A and B are points at which the current leaves the sheet. There is no appreciable distortion at the edges.

Mr. Trotter.

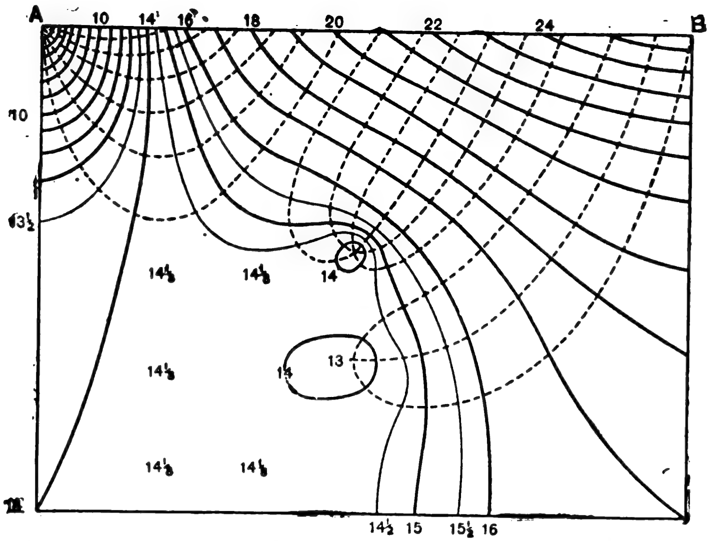


FIG. C.—A B is the line into which the current is fed. Some of it leaves the sheet at A, but at two points on the sheet "out in the open country," the potential is reduced to 13 by tapping out some of the current, leaving a considerable space at a nearly uniform potential of 14⅛.

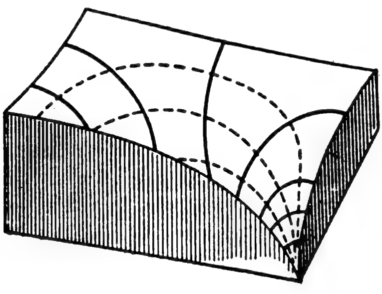


FIG. D.—Model of Fig. A in the solid.

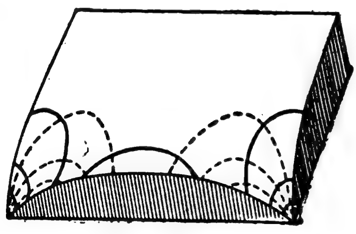


FIG. E.—Model of Fig. B in the solid.

of the earth is indicated by them. That potential is represented by the plane to which the surface of the model is asymptotic. It is generally assumed that the most negative point is at the undisturbed potential, and that all the disturbance is positive. The conductivity of the rails is not taken into account, no current therefore re-enters the line A B as it does in practice.

Mr. E. O. Walker.

Mr. E. O. WALKER: I am reluctant to speak after Mr. Trotter and Mr. Parry, because of their great knowledge on the subject; I will therefore only make a few brief remarks. We found in telegraph work in all the experiments we have made with regard to earth connections that the surface, for certainly four or five feet down, is practically non-conductive. I think we have got, generally, as much as 1,600 ohms

Mr. E. O. Walker.

with a square foot of metal plate exposed to the soil within those limits of depth. It appears to me with regard to these currents which stray from the end of the track away from the generating station, that they do not take the path which they are supposed to take near the surface. We found that if we went down a depth of 30 or 40 feet with the metal plate we got very often into good conducting strata; evidently the water-bearing strata. The upper part of the earth is only slightly moistened when there is a heavy shower; the moisture does not penetrate down very far; consequently what we have to depend upon for good earth is the moisture that comes upwards by capillary attraction from the springs and streams which are deep down. So that if pipes, such as gas and water pipes, are near the surface of the ground, it is not very likely that they will be subject to the corrosion which has been anticipated, and which has not always been proved to exist. Then, again, with regard to the time element, when a line or pipe is first laid, of course the surface is well exposed to the surrounding soil, but it appears that oxidation caused by electrolysis necessarily heightens the resistance between the faces of the rails and the pipes and the soil which surrounds them, so that in time we must expect that the electrochemical effect upon the metals will grow less. In reference to the remarks made in the paper with regard to the ordinary chemical action of soils, I think the damage done is very much larger in extent than any possible damage likely to be done by stray currents.

I noticed in a paper in the *Electrical Review* some few months ago that it was stated with regard to American practice that ground plates had been tried in connection with tramway tracks in America, and that in a few months time the amount of current passing through those plates decreased by twenty times, due, of course, to the oxidation which had taken place, which is really a protective coat to any pipe that is buried in the ground, as well as, I presume, to the under surfaces of the rails. With regard to the disturbance which has been noted laterally to a line, I think that if you go laterally five miles away from any of these electric trams, running perhaps two miles in a straight line, you will find there is a disturbance due to a want of balance of that system, even if the whole of the current is confined to the rails and none of it strays into the ground. I have tried unbalanced systems as regards telephone disturbance, and concluded that certainly at five miles distant the effect on a telephone line would be very perceptible indeed, owing to the want of balance between the current in the trolley wire and the current in the nearest rail to the place of observation. Suppose the trolley wire is in the centre of the track and there is a distance of about 2½ or 3 feet, measured horizontally between wire and rail, the difference of current in the trolley wire and in the rail is so pronounced that a magnetic disturbance must be created in any lateral direction.

Mr. S. F. Walker.

Mr. S. F. WALKER: I propose to attack the theory that has been set up that the earth is to be considered as one homogeneous conductor, and that practically it does not matter where you lay your track, and that the pipes present in the ground do not make any difference. If we take it either on theoretical considerations or on practical considera-

tions, we cannot help questioning these statements. For instance, what have we in the ground to conduct apart from the rails? We have got an aggregation of minute particles—I am leaving out the moisture for the present. Supposing that you take an absolutely dry soil, if you can have such a thing, you have an aggregation of very minute particles of a substance which in itself has a high specific resistance, and those particles are arranged together in such a manner as to offer a very high resistance. I think it follows, and from our practical experience we know that it follows, that for all practical purposes the conductivity of the earth is by way of the moisture which is held in the ground. The moisture in the ground is partly a question of the weather. As the last speaker said, it is quite correct that the surface of the ground, in some cases, merely gets wetted temporarily and the water drains off, and that you have the ground lower down holding the water-bearing strata, the moisture. But, wherever it is, it is the moisture that conducts, *plus* whatever conductors you may have embedded in the ground if the current can get to them. I think we must take account of pipes and all kinds of things which are buried—gas pipes, water pipes, and other pipes—because I think we must remember also that a great number of these pipes, at any rate, are connected to masses of metal above the ground. We must consider that all of these pipes take part in the action of conducting any stray currents which they can get hold of. The question of whether they can get hold of the currents and how they get hold of them would depend entirely, as has been stated, on the surface resistance. Mr. Parry is quite correct in saying that the resistance between the rail and the ground around it, and between the ground and any pipe buried in the ground, is usually very high. It is very much higher also as time passes on and a film of oxide forms on both pipes and the under surface of the rails, and so on, but I do not think we can help thinking that some current will get into those pipes, through that oxide, and that they must take a large share in conducting leakage currents. Mr. S. F. Walker.

Then there is another question, which I am very pleased to see has been tackled, which Mr. Trotter and others have mentioned, namely, what is the earth potential? I do not think anybody can say what the earth potential really is. You may know what the potential at a particular spot is at a particular instant, but you cannot say that it will be at the same potential at the instant after or that it was so at the instant before. So that in considering the earth potential you are dealing with a constantly varying quantity, and the whole problem becomes very much more complicated than it looks at first. Then there is a question of the electrolytic action of the current in the pipes; that may be looked upon as not a very serious matter, but I fancy that waterworks engineers would look upon it as a serious matter. One of the great troubles which waterworks engineers have is the filling up of their pipes, and I think we know that if stray currents get into their pipes they very much assist chemical action between the water and the pipe inside to form nodules, and these when formed increase the resistance to the flow of water in the pipes. The resistance offered by a pipe to the flow of water varies directly as the

Mr. S. F. Walker. surface of the pipe over which the water passes, and also directly as the square of the velocity of the water. Nodules formed by chemical action increase the interior surface over which the water passes, at the same time reducing the sectional area, and therefore with a given delivery, a given number of gallons passing per hour, or per minute, increasing the velocity at which the water must travel.

Mr. Sayers. Mr. H. M. SAYERS: I have listened with great interest to the methods laid before us, and the theoretical dissertations as to the exploration of the stray currents from traction systems. To one who has to deal with these things practically, the methods of measurement are of great interest. In actual work, of course, we have very slight means of finding out what the leakage from our tracks is. We are compelled by the Board of Trade to bury earth-plates, and to observe or record the current flowing back to the station through those earth-plates. Obviously that current is only an exceedingly rough indication of the true leakage current from the rails; such leakage current, where a simple system is in use without boosters, must be at a maximum, measured on a surface normal to the track, somewhere about the potential middle of the line. It is not in the maximum at the station, or one would not expect to find it so. Mr. Trotter's models, if sectioned, will, I think, bear that out. I would like to know how a magnetometer method will be affected by the very frequent case—which becomes more frequent as networks of lines are built—of feeders being taken across country not parallel with the track or trolley wires. It appears to me that the current in those feeders will be difficult to make corrections for, and that the results with the magnetometer will not be very trustworthy. However, it is something to find that in simple cases the measured do correspond with the calculated results, as it gives us a safe theoretical basis for calculation.

Something has been said about the character of earth conduction. I have had occasion in a few cases to find very curious effects in difference of conductivities, in different layers of the earth. I know one part of the country where the earth is divided into alternate sheets of fairly good conductors and fairly good insulators, and in tracing stray currents from cable faults, and the like, I have been very much led astray. I have had one case of a tramway which shows a marked difference between the conductivity of the track in dry weather and in wet weather. In this particular case, on a thoroughly wet day, the amount of stray current returning by the station earth-plates, and the drop of potential in the rails, is distinctly lower than it is in dry weather. That points, I think, to the fact that the thorough wetting of the sets and the mud and the concrete, increases the conductivity of the track as a whole. It also seems to indicate that the probable leakage into the earth is in a vertical, and not in a horizontal, direction; which bears out what has already been said here as to the comparatively poor conductivity of the upper surfaces of the earth. However, that was only one observation, and there may be something peculiar about the conditions.

I only wish to say a few more words on one subject, viz., on the much-debated electrolytic action upon pipes. M. Claude's paper,

which has probably been read by everybody interested in the subject, is confirmed by a great many other observations; but I think no one has put together so many facts to show that the conductivity of the earth as a whole is not an electrolytic conductivity; it is in the nature of a solid conductivity. I have had the opportunity of examining some tramway rails which have been in use for nearly nine years. They have been used under the Board of Trade Regulations—not the present Board of Trade Regulations, because the volts are not limited to seven. If Mr. Trotter were not here I would say how many volts are used. Of course they ought to be limited to seven. The rails that I examined were at the most distant point from the station. I was very careful to look at them for any signs of pitting or electrolytic corrosion, but failed to see any. The buried surfaces were a little rusty, as those of any rails would be that had been laid for eight or nine years; but it was the ordinary red mixture of oxides and carbonates which one sees, and there were no indications of the black pitting which one finds where real electrolytic corrosion has occurred. It seems to me that such substances as the oxides and silicates of the alkaline and earthy metals, which compose the bulk of the earth's surface, probably act in the nature of depolarisers; they may take up any free acid which may be produced by the passage of the current, and thus protect the metal: that is only a suggestion, which may be quite wrong. The question as to bonding pipes to tramway rails is a very important one. I think M. Claude's experiments show that pipes are, on the whole, safer when they are not connected to the tramway track. It is perfectly true that you can make such a connection, and that no part of the pipe should be positive to earth. If one could only be sure that the pipes were either metallically connected throughout, or that they were all very badly connected, making very bad joints, electrically speaking, one would feel assured that they were quite safe. But the conditions likely to occur are, I think, that for a long length of pipes, joints may be good electrically speaking, but that here and there a bad joint will have been made; and, under those circumstances, with the considerable current gathered from the earth flowing through the pipe, there may be a dangerous difference of potential across one or two of the joints. When the pipes do not belong to the tramway, and when the tramway engineer has no means of ascertaining their condition, and the man who laid them has no idea of what electric conductivity means, it does appear to me that it is a counsel of safety not to connect the pipes; but the case is quite different when a man who has some knowledge of electrical matters has to lay a line of pipes which he knows are exposed to dangers from tramway currents. I have had to consider this in laying pipes for tramway feeders. It is almost impossible to prevent the pipes that carry these feeders from being connected to the rails at distant points. They come into contact with the iron of feeder pillars. We bond our feeder pillars deliberately to the rails, for reasons which are well known. What is the best condition of safety then? The practice which I have followed, and which I hope will have made my pipes and also my cable-sheaths safe, is this: in using cast-iron pipes a few chisel cuts are made in each spigot and socket just before the lead joint is Mr. Sayers.

Mr. Sayers. made, an attempt being thus made to render the lead joint a good conducting joint. At each place where the line of pipes is broken by a joint box or inspection boxes, it is bridged across by a wire of sufficient size, properly secured to the pipes. At the station the pipes are thoroughly bonded to the negative 'bus-bar. I am quite aware that under some conditions the cast-iron pipes may suffer even with all that care; but I do not think they will suffer a great deal. What I do feel very confident about is that the lead sheathing of the cables will be protected as long as there is a fragment of cast-iron round them.

Mr. Adams. Mr. A. J. S. ADAMS: I regret very much the unfortunate title to this paper. The term "Earth Currents" for the last thirty years has governed the study of those cosmic electrical variations which ally themselves to the variations of the magnetic needle, and I certainly hope that when we have this interesting point to discuss at a future meeting it will be under another name. There is a vast difference between derived forces and the cosmic earth currents. If you will apply to the Astronomer Royal no doubt he will permit you to look up the old records, and you will find for at least twelve or fifteen years the photographic records of the true earth currents. Whereas now, you will find that during the hours at which the South London Electric Railway is working, those records pick up little else than the current from the Electric Railway. It is the same in my own garden at New Cross. I have photographic apparatus there, and by putting the two ends of my galvanometer into my garden, say ten or fifteen yards apart, I can during the daytime pick up the currents from the Electric Railway; and I therefore feel rather at enmity against these traction people on that account. Another point is that before we can accept the assumptions of this paper, we should know whether we are dealing with leakage and spread, or with magnetic radiation. The point is not clear.

Mr. Mordey. Mr. W. M. MORDEY: I am glad Mr. Adams has spoken about true earth currents. This Institution started as the Society of Telegraph Engineers. In the early days earth currents were considered a good deal, on account of their bearing on telegraph working, as may be seen by the records of some of our early meetings—there are eighteen papers on the subject in the first ten volumes of our Proceedings. Telegraph engineers need not be reminded that all the old needle instruments were made with rotary dials, so that, when earth currents came on, the dials could be turned round to bring the needle to the middle position whatever the force or direction of the earth current might be. I remember, when I was in the telegraph service, measuring earth potentials on a line seventeen miles long, and finding forty Daniell cells necessary to counteract the earth current. That meant a potential of nearly two volts per mile. I remember at the same time I ran a little electric motor by those earth currents on the telegraph circuit. That was long before tramways or electric light. I suppose nowadays we should be told that that motor was being run by leakage currents from tramways, and that it was therefore impossible to have any observatories anywhere near such lines. We must recognise the necessity for distinguishing, as Mr. Adams has done, between real earth currents and leakage currents. The gas companies ought to have a great grievance

against Nature. There really ought not to be, according to the evidence that we have heard within the last few months, a gas-pipe in existence, not because tramways have been started within the last few years, but because the earth has always had currents travelling in it. We have heard a good deal about the scientific study of these things. It would be, perhaps, unkind to refer very particularly to the difference between scientific evidence and practical results—to what we were assured was the amount of the absolutely unavoidable electrolytic wasting away of the pipes, of which, as the author points out, only four per cent. occurs actually in practice. I will only say that I am sorry Professor Ayrton and Professor Perry are not here that they might hear the views of practical engineers on that subject. Mr. Mordey

Mr. S. WOODFIELD (*communicated*): Speaking on Mr. Wedmore's paper from an engineering point of view, the magnetic effects are secondary in importance to the leakage earth currents, although the former are of considerable interest from the scientific side of the question. Obviously, in a traction system we can cut down these earth currents practically to zero by using an insulated return conductor, but in an overhead trolley system this would result in almost insuperable difficulties, as one can easily see by visiting certain junctions and crossings on the tramway systems of Glasgow or Liverpool. In the conduit or surface-contact system the difficulties are not so great, but in all cases the capital cost would go up enormously. It is fairly well established that the corrosion is due to the metal of the pipe being attacked by the acid radicals contained in the salts of the alkali-metals in solution in the electrolyte, the salts in solution being electrolysed, and the acid radical attacking the anode. It would appear, therefore, that if we could be sure of always keeping all points of the rails at zero potential, no bad result would accrue. It is a mistaken idea to think that if we keep the potential difference below that requisite to decompose water, we cannot do any damage. It has been stated in the paper that the apparent resistance between the rails and the earth is constant; but this, however, I do not think is the case, as I have several times noticed on the recording voltmeters in the stations that the drop in the rails is considerably less on a thoroughly wet day to that noticeable on a dry one. Mr. Woodfield.

Again, I have repeatedly found that the leakage current returning through the leakage ammeter to the station is increased in wet weather. It is possible that in wet weather, more especially in towns, certain salts in the earth are dissolved, or that the rain mixing with certain acids (which will always be found in large towns) produces a path of lower resistance than there would be in dry weather. It is clear that, in a given time, the amount of corrosion will depend upon the quantity of current flowing and also upon the salts in solution in the electrolyte. I quite agree with the author of the paper when he states that these effects are much exaggerated. I have continually had brought to me the lead-sheathing of cables and lead water-pipes pitted with holes, the owners stating this to be due to electrolysis by leakage currents; whereas, in many cases, I have found the pitting to be due to certain acids, notably acetic acid,

Mr. Woodfield.

It has been suggested that if the polarity of the trolley wire were continually being reversed, say every few hours, the electrolytic effects would be cut down to a minimum. This method has proved successful in the laboratory, but in practice it has been found to have little or no effect if reversed every twenty-four hours; on small systems, however, there appears to be absolutely no reason why the reversals should not take place every few hours, as it would not necessitate reversing a very large current, as would be the case in some large power-houses. In this country the Board of Trade state that the positive pole of a generator shall be connected on to the trolley wire; whereas, in the United States many of the lines are connected with the negative pole of the generator on to the trolley wire. In the first case, the current will leave the rail at distant points and enter the water or gas pipes running along them and leaving them in a position near the power-house and joining the rails. In this case a vast amount of damage will be done to the pipes within a certain area around the power-house, no damage, of course, being done to distant places. In the second case, however, the current would leave the pipes and flow into the rail at remote places, and although the same current would leave the pipes, yet it would be distributed over a far greater area, and consequently the density would be greatly cut down and therefore the electrolytic effect would be less. Against this, however, it must be borne in mind that a far larger area is affected, and it is only a matter of time before serious trouble would accrue.

As Mr. Wedmore has pointed out, the bonding of the pipes to the negative 'bus-bar would increase the current flowing in the water pipes, and although no effect would be produced at the point where the current enters the cable from the pipe, yet at every joint, owing to its resistance, current would leave the pipe and join it again after the joint was passed; thus it is evident that we are in no way minimising the trouble, but, on the other hand, affecting all the pipes where the current leaves.

Since the introduction of negative boosters, it has been the general practice to lower the potential of the rails at the point where the negative cable joins them to a potential considerably below that of the adjoining earth, and it will be found that in many stations it reduces to a great extent the apparent voltage-drop on the rails. But on looking further into the question, one sees that by lowering this point to a potential below that of the earth around it, one is increasing the potential difference between any neighbouring water-pipes and that point, thereby increasing the current flowing in the pipes and obviously therefore reducing the drop in the rails. As a fact, the booster should generate across its armature a voltage practically equal to the voltage-drop in the negative cable with a given current flowing. The voltage across the armature is, to all intents and purposes, proportional to the current flowing around its fields and on to the line. It is a mistake to connect one booster to three or more negative cables having various voltage-drops in them, since if the series coils of the booster be shunted to give the correct pressure for one point, it is evidently wrong for others of different distances. I should like to ask

Mr. Wedmore if he has found greater magnetic effects produced with lines supplied with rotary converters, than from lines supplied with ordinary direct-current railway generators, as in some cases with rotary converters the pulsations vary between 30 and 40 volts. Mr. Woodfield.

Regarding the double trolley wire, I understand that it is used at Strassburg, where considerable external magnetic effects were produced, and that it has not done away entirely with the upsetting of the magnetic instruments.

Mr. E. B. Wedmore, in reply, said: There are a few points raised by various speakers to which I would like to reply quite briefly. First, with regard to Professor Glazebrook's letter, I note that the Professor calculated the horizontal and vertical disturbances, but has not published the figures he calculated on the horizontal disturbance. It seems to me, in going over Professor Glazebrook's figures, that to obtain the agreement that he did he was bound to choose the points which he did, viz., the two points at the utmost extremities of the line. Professor Glazebrook assumed a leakage current, and then found two points which gave approximate agreement between the calculated magnetic effects and the observed magnetic effects. I found by trial points which would fit in with various theories which I have had before me from time to time, and by juggling with these points sufficiently I found I was able to get a certain amount of agreement. I set all this aside, however, and chose points which seemed to me to be about representative of the centres from which the currents might be taken as leaving and entering the rails, taking into account the probable distribution of potential along the track. It was only after I had calculated the results from those points that I began to find out that the peculiarities in the results were really only reasonable peculiarities such as one might have foreseen. I should like to say also that I think the leakage current which Professor Glazebrook assumed from the only data apparently available might really have been much larger than he took it. I do not know what the regulations are under which the Spandau tramways are worked, but they are not English Board of Trade regulations, and it is quite possible that the leakage there may be very much bigger than would be allowed over here. I believe my figure of 60 amperes is a bigger figure than one ought to obtain under Board of Trade regulations for a line of that size. With regard to the agreement between Professor Glazebrook's formulæ and the formulæ that I give, I had noticed the agreement, but did not draw attention to it. It seems to me the formulæ is a simple thing to arrive at, once the principle has been developed. I think that the principal justification of the calculations I have given lies in the agreement obtained between the horizontal and vertical disturbances, and I believe my calculations are the only ones which show that agreement. Mr. Wedmore

Mr. Trotter has referred to the measurements made on the London United Tramways line. I should like to add a few remarks with regard to these measurements. In the first place, I have stated in the paper that the disturbances appear to have been due to a traction system. I have stated that they alternate in direction, but I should like to add that the curves plotted as the result

Mr. Wedmore.

of readings taken every few seconds give the same sort of curve as one obtains on a recording ammeter, a curve having about the same fluctuations as are obtained in the current in a traction station. These fluctuations agreed approximately with fluctuations observed in the magnetic effects measured at a point not very far off at the same time. So I think there was pretty strong evidence in that case that the currents were not normal earth currents, but were due to a traction system. During the night-time, when the tramways in London are shut down, there was a small reading shown all in one direction; if I remember right, it was of about one-sixth of the maximum amplitude of the fluctuating reading. That may have been earth current or it may have been leakage from some of the direct-current lighting systems; I should not like to commit myself on that point. Mr. Trotter has raised a rather important point in connection with the distinction between the direct measurement of current and its measurement by measuring potential difference, and assuming that measurement as a basis for calculating the current. I have heard Mr. Trotter speak on that subject before, and never quite grasped the point. It seems to me that the point is this: If you take a very large system, a very large area, and measure the potential difference between two points very distant in that area, each of these points having a very good earth connection, the measurement you obtain must be fairly representative of the actual difference of potential in volts between the body of the earth at the first point and the body of the earth at the second point, and if there are no E.M.F.'s in the circuit other than that measured, then you may use that E.M.F. to calculate the current which is flowing between those two points. If, however, you stick two rods into your back garden and take measurements between those two points, the local variations are so great that the result would be exceedingly unreliable as representative of the effect occurring over the surrounding area. The mere thrusting of the rod into the earth, too, might be sufficient to make a difference in the results. The measurements made on the London United Tramways system before the generators were running, over an extent of some 2½ miles where the contact between the line and the ground was good, are of a kind which would be fairly reliable.

I did not have water-pipes or waterworks in my mind when I referred to electrolysable liquids, although I cannot recall to mind at this minute any case where electrolysable liquids are carried in iron pipes, but they may come along soon.

Mr. Parry has raised several interesting points. I should like, in the first place, to disclaim what I thought I had never claimed, viz., that I should advocate the general use of a magnetometer for measuring leakage currents. It was not my intention at all. I have taken certain isolated facts, made certain assumptions, and evolved certain theories. I have collected such extraneous evidence as I could find to support my assumptions, and I have endeavoured to show that the theories are in accordance with the facts. I have demonstrated how the whole thing hangs together, and this is the strongest proof that each part is in itself not far from the truth. I was glad to hear one

speaker say that he thinks a magnetometer method may be of value in some cases. Of course in certain isolated cases you may find that you can arrive at the results you want by one of these roundabout methods. With reference to the resistance of the earth, calculated at 75 ohms per yard cube, if the assumptions made are not correct, I have already shown that the earth resistance must be lower than that figure. If the currents did *not* flow through large sheets or through a large body of the earth, or if there *are* other resistances than those I have taken into account, or other E.M.F.'s, then the specific resistance of the earth itself must be so much the lower. I have taken one very large portion of the path. If that portion is not the only portion offering resistance, then the resistance of that portion must be very much lower than I have figured it at. One speaker made use of the term "1,600 ohms per square foot." I have noticed a similar use of terms in several articles bearing on this subject. It seems to me that the expression "ohms per square foot" is incorrect. I use the expression "ohms over a square foot" to get over the difficulty. The resistance is not proportional to the area; the resistance is inversely proportional to the area. Mr. Wedmore.

Referring again to the vexed question of the path of the current through the earth, I have shown that it is impossible to determine by means of magnetometer measurements whether the current streams are confined to a layer or not. The question must be settled by measurements of difference of potential, taking into account the specific resistance of the earth. It is probable that both assumptions are false and that both assumptions are true. Some current must flow into all parts of the earth, and yet the bulk of the current may flow near the surface.

I have always been under the impression that electricity, although only in its infancy, is pretty much the same wherever you find it. Electrical energy at 6d. a unit is no better in quality than electrical energy at 2d. per unit. I have an idea that tramway engineers can put as good a current into the earth, and certainly as strong a one, as any that has been found there since the early days of telegraphy. Hence why should the telegraph engineers have a monopoly in the use of the term "earth currents"?

The PRESIDENT: I will only detain you a moment in order that you may testify to Mr. Wedmore, and to those gentlemen who have taken part in the discussion, your appreciation of their contributions to this subject. The paper is a most interesting one, and has elicited a very interesting discussion, although the subject to which it refers is a very vexed question. If we could only find an instrument which would be reliable for the ready measurement of currents passing over the surface of the earth, it would no doubt be acceptable in many quarters. The President.

I can support Mr. Trotter in his reference to the difficulties sometimes met with in obtaining earth, as well as in his observations on the natural currents which traverse the crust of the earth. These natural currents are frequently very powerful. The difference between the natural currents and the artificial currents may perhaps be defined in that whereas the artificial currents permeate the surface of the earth

The President.

only in the neighbourhood in which they are generated, the natural currents are practically universal, although only occasionally with any degree of force.

I will now ask you to pass a very hearty vote of thanks to the author for his admirable paper and to those gentlemen who have taken part in the discussion.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

As Member:

E. J. Bristow.

As Associate Members:

Dawson Adams.
Stephen E. Bastow.
Edward Dewar.
Robert Kemp.
Percy Lampard.
Henry Augustus Ratcliffe.
Oliver Shiras.
Malcolm Greeves Smyth.
Arthur J. Wheatley.
Roland Spenser Yates.

As Associates:

Edward Ernest Anderson.
Frederic H. P. Berlyn.
Francis Chas. E. Burnett.
Tom Charles Collins.
Edward Brown Cook.
William Henry Cook.
Edward B. Ellice-Clark.
Percy Burnett Hall.
Percy M. Hampshire.
William Scott Harland.
James Archibald Kyle.
Alfred Reginald Munro.
J. W. Ormiston, Major R.A.
Clifford C. Paterson.
William Clapham Priestley.
Wm. Henry Starkey.
Frederick Walton.
Herbert Wm. L. Ward.
Henry Wolfenden.

As Students:

Alfred Spencer Briggs.
Herbert C. Crook.
Francis T. Fawcett.
Henry James Few.
Cecil Herbert Finnis.
Geo. William Fisher.
Chas. Francis Jeffery.
Edward M. Langley.
B. Leigh.
Wm. P. Miller.
Frederick Neuhaus.
Howard Potter.
Percival H. Powell.
Alfred Roberts.
Godfrey J. D. Scott.
Alfred Somerville.
Malcolm C. Timms.

DUBLIN LOCAL SECTION.

AN ACCOUNT OF THE VISIT OF THE INSTITUTION OF ELECTRICAL ENGINEERS TO GERMANY, JUNE, 1901.

By PERCY S. SHEARDOWN, Associate Member.

(Paper read at Meeting of Section, November 14, 1901.)

The Institution's visit to Germany this year was intended to be a combination of instruction and pleasure; and although in the following description I have no time to dwell on the pleasure side of it, still it was certainly there; indeed, I have rarely enjoyed a trip more, which was partly due to the kindness of our German hosts and partly to the general "good fellowship" that pervaded the whole party.

The germs of this trip were sown in 1899, when the Institution visited the power-stations and works in Switzerland; the managing director of the Allgemeine Elektricitäts Gesellschaft conveying an intimation that the German electrical firms would be pleased to show what Germany could produce in the way of works, manufactures, and power-stations. On the invitation being accepted, our hosts seem to have laid themselves out not only to show us the extent of their engineering enterprise, their modern works and colossal power-stations, but also, and in no less a degree, their hospitality and power of entertaining.

The visiting party were divided into three groups. Members of Group A. visited Hanover and Berlin only, which occupied about a week; members of Group B. went on to Dresden, where they met the German Institution of Electrical Engineers, and returned to London from there; members of Group C. continued their journeyings to Nürnberg and Frankfort, and travelled home down the Rhine.

The party which left Liverpool Street station by special train at 7.45 p.m. on Saturday, June 21st, numbered about two hundred; it was officially in charge of our Past-President, Mr. Alexander Siemens. On the 22nd, at Hanover, tramcars were waiting to take members to the works of Messrs. Körting Brothers, celebrated for the manufacture of injectors, heating apparatus, and gas engines, and also to the electricity works of the city. There appeared to be in Hanover an extensive electric tramway system, as I noticed the car numbers ran up to 700.

The system generally is the trolley-wire type; but the cars, instead of being equipped with a trolley standard and pole, are provided with the Siemens type of collector or bow.

Trail cars are run, some of the motor cars hauling more than one trailer. A few of the cars had top seats, but the single-deck car is almost universal on the Continent. There is no trolley-wire allowed

to mar the appearance of the principal streets; but the cars run through these streets driven by energy stored in a small set of accumulators stowed away in each car, and charged from the trolley-wire during the cars' peregrinations in the suburbs. This system was in vogue in Hanover, Berlin, and Dresden, there being no trolley-wire in the principal show streets. Although from an æsthetic point of view this system appears very good, still, I gathered from good authorities that the maintenance of the batteries was a very costly matter—in fact a veritable profit-eater.

In the evening the members and ladies of the party were invited by the City of Hanover to a banquet.

In Berlin we were the guests of the two eminent firms—the Allgemeine Elektricitäts Gesellschaft, and the Siemens and Halske Company. The programme for the afternoon of the 23rd was a series of visits to the electrical supply stations of Berlin.

Meeting in the council-room of the Berlin Electricity Works, we were first of all treated to a paper on, and a demonstration of, the Nernst lamp, as manufactured by the A. E. G. Company, who are proprietors of the original patents.

Electricity for power and light is supplied to Berlin from six large central stations, which are the property of one company, formerly known as the German Edison Company. This company has a special agreement with the municipality, which includes the payment to them of a certain share of the profits and also includes a purchase clause.

The station which we first visited is composed of an old station known as the Schiffbauerdamm station, with a large addition known as the Luisenstrasse station. In the former are three 1,000 H.P. vertical compound Corliss engines, each direct-coupled to two generators of a very curious type, which, although used to a certain extent on the Continent, have, I think, never been copied in this country. In this type the fields are stationary, and project out radially. The ring-wound armature is external to the field poles, being supported and driven by a spider. The inside portions of the winding are the active bars; the outside or top portion of the bars are bare and are used as a commutator, the brushes therefore collecting the current direct from the armature. Each machine is capable of generating 2,600 amperes at 140 volts, the system being a three-wire continuous one at this voltage. There are also in this portion of the station two 2,000 H.P. direct-coupled inductor alternator sets, working at 3,000 volts three-phase. This part of the plant, it was explained to me, was really an extension of a direct-current station close by at Markgrafenstrasse, where it was impossible to get in any more generating machinery, but which required more power for the network connected to it, the whole of this alternating power being transformed down there and distributed from its 'bus-bars. This seems a curious solution of peculiar local conditions.

In the Luisenstrasse station, which is a still later addition to this power-house, there are three magnificent generating sets of the very latest type. Each set consists of a triple-expansion vertical Sulzer engine, coupled, one on each side, to two continuous-current generators of 1,000 H.P. generating at from 250 to 280 volts. These machines are

used in parallel to supply the outers of the 140-volt three-wire network, or in series to supply current at 500 volts to the tramways. The water-tube boilers of this station are placed on the floor above the engines, and supply steam at 200 lbs. pressure, which is superheated to a very high degree. These sets, it is said, can generate a kilowatt-hour with an expenditure of a little over $1\frac{1}{2}$ lbs. of coal.

We then visited the Moabit station of the Berlin Electricity Supply Company. This is one of two high-tension generating stations built by the company outside the city. It is at present equipped with three sets of plant, a fourth being in course of erection, but they are magnificent examples of modern electric generating sets. The engines are of the triple-expansion horizontal type, each having four cylinders arranged in two lines, tandem fashion. The alternator is mounted on the crank shaft between the two lines of cylinders, and generates a three-phase current at 6,000 volts. When complete, this station will have installed 36,000 H.P. The switch-board is erected on a gallery commanding a good view of the engine-room below. The panels carrying the instruments are of white marble. The run of the leads and connections seemed well arranged, porcelain insulators being largely used.

Our next visit was to the rotary converter sub-station at Königin Augusta Strasse. This sub-station was interesting from the curious type of converter installed. One great disadvantage experienced with rotary converters is the difficulty of varying the direct-current voltage when the alternating supply pressure must be kept constant. The American practice is to put a reactance coil between the transformer and the machine, which latter is compound wound, but with this arrangement the range over which the voltage may be varied is very limited. The design employed in these A. E. G. rotaries, and which is due to Mr. Dobrowolski, the company's chief designer, is as follows:—The machine has two armatures on the one shaft, and two sets of field magnets. The alternating current first enters one armature by three slip-rings, and then passes into the other and out by a commutator. The first machine is an alternating booster, the fields being separately excited. The amount and the direction of boost can be varied, I understand, 20 per cent. either way. This appears a very satisfactory solution of this problem, but at the same time I should think a very expensive one, as the booster appeared about half the size of the rotary, and would, I should think, add 40 per cent. to the price of the latter.

Tuesday, 25th June.—The visits for this day were arranged by Messrs. Siemens and Halske. The history of this firm is most interesting, and a paper on it alone would be very instructive. The firm was founded in October, 1847, by Werner Siemens, an artillery lieutenant, and Halske, a mechanical engineer. The small shop at this time contained three small lathes and ten workmen. They were first engaged in the manufacture of needle telegraph instruments, and gutta-percha covered wire. The pioneer telegraph work they did in Europe was enormous, and in 1853 they laid the first submarine cable between Oranienbaum and Kronstadt, which has been working ever since. In 1866 the first dynamo machine was manufactured. In 1872

the firm were employing 543 hands. In 1879 they produced the first differential arc lamp, and so well have they kept up with the times that at the Paris World's Fair they were awarded the highest prize of all those awarded to dynamo electric machines, for a 2,000 K.W. steam dynamo.

The success of the enterprise of this firm in developing every new application of electricity has been so great, that at the present time the sister houses of Berlin, Vienna, London, and St. Petersburg employ 15,000 workmen and 4,000 officials.

Starting from the Weidendammer Brücke, we were taken by special steamer down the river Spree to the cable works at West End. These cable works, which were built in 1883, extend over six acres of ground, with a brass foundry covering half an acre.

The feature, I think, that impressed us most about these works, and indeed about many others that we saw in Germany, was the amount of room, and hence absence of crowding; the whole of the buildings were kept scrupulously clean, all waste or scrap material being at once removed and so there was no litter; they were lofty, and had plenty of fresh air and light. Naturally, under these circumstances the working employés looked healthy, happy, and interested in their work. We were conducted through the various shops in groups, by members of the technical staff; everything was open for our inspection and all questions asked were answered without reserve.

Every class of cable was to be seen, in all the various stages of manufacture; and so much of it was there to be seen, that two hours' steady tramping round barely sufficed to show us the whole of the works. I will not describe these works in detail, as the description of one I think will suffice, and from notes supplied I prefer to go into more detail about the Oberspree cable works of the A. E. G. which we visited next day.

At noon we embarked on our steamer again, lunch being provided *en route*, and so arrived at the Siemens and Halske works at Charlottenburg.

The firm had taken much trouble to make the visit both interesting and intelligible, the chief objects of interest in each department being numbered, and we were each supplied with a type-written catalogue.

The first and most interesting subject touched on was a group of exhibits in connection with the electrical equipment of a new high-speed car. The energies of this firm and also of the A. E. G. Company appear at the present time to be concentrated on this modern development of high speed. The particular one that we were shown was ordered for experiments at high speed, on the military railway between Berlin and Zossen. The arrangement they had erected in the testing-room showed us in outline the electrical equipment and general arrangement. The three-phase currents that operated the car were generated by a 700 K.W. dynamo which was really intended for coupling to a turbine, but in the present instance was being rope-driven by a motor. It was generating current at 10,000 volts, which is the pressure they intend to use on the trolley-wires. By a suitable collecting arrangement the currents are led into the car. A first

branch leads to a small auxiliary transformer with a transformation ratio of 10 to 1; this furnishes current to two air-compressing motors (compressed air being used to operate both brakes and switches). The current then passes through two high-pressure switches, one arranged at each end of the car. These switches are of what the firm call the tube type, which is designed so that the arc formed on opening the switch is drawn into a narrow insulating tube, the extinguishing effect of which is increased by metal cooling-rings. From the switches the current passes through some main safety fuses, which are designed for destroying the arc in the same way as in the tube switches; the melting strips being enclosed in narrow insulating tubes open at both ends, the action depends on the vapours (which are developed with great vehemence by the melting metal) suppressing the arc. The main transformers (there being one on each truck) reduce the pressure from 10,000 volts to 2,000. These transformers, which are pierced by longitudinal slots, are placed under the car, so as to get the full benefit of the draft (created by the car when travelling at high speed) for cooling purposes. The primaries of the transformers are permanently connected in star fashion, but the leads from the secondaries are led to switches (which are operated by compressed air) by means of which they can be grouped either in star fashion, producing 2,000 volts for starting, or delta fashion producing 1,150 volts for normal running. These secondary switches, with the motor switches and fuses, are arranged beneath the floor of the car near the transformers, the 10,000-volt switches and fuses being kept away separate on the roof. The motors, two to each truck (there are two six-wheeled bogie trucks for each car), have a normal output of 250 H.P. each, and are able to stand an overload of 1,000 H.P. for a short time. The primary 2,000-volt three-phase current is led into the rotor by three slip-rings, the induced current from the stator is led from the latter to the starting device which consists of three drums or cylinders, the movement of which, operated partly by compressed air and partly by hand, cuts in or out resistance in the stator circuit. The compressed air is furnished by two air-pumps geared to induction motors of 3 H.P. each.

It would be impossible to give anything like a complete list of all the interesting apparatus and machinery we saw in these works, but casually I may mention electric mining locomotives, automobile motors, all kinds of electric tramway apparatus and material, electric ship-steering apparatus, etc. In the large machine hall we saw a fine display of big generators, many of the alternators being for three-phase work, the pressure in some cases being produced in the machine as high as 13,500 volts.

The alternators were usually of the stationary armature fly-wheel type, the armature cores being slotted to receive the winding in the shape of a former-wound coil, which is held secure in its place by a wood or hard asbestos key. This method is, of course, the almost universal practice; one of the greatest advantages being the comparative ease with which a damaged coil can be replaced.

There was also a large towing electric locomotive which travelled with the wheels on one side on a rail, but the other wheels, which

were provided with tyres of suitable breadth, ran on the tow-path. It was driven by a 16 H.P. motor, which took current at 500 volts from a trolley-wire, and developed a tractive effort sufficient to pull two barges of 300 tons capacity each, at the rate of from two to four miles an hour.

Then there was on exhibition a lot of electric rock-drilling machinery; also in a department by itself a splendid display of railway block and other signalling apparatus, which Siemens and Halske have made a special study of. Their electric switch and signalling arrangements, which allow of great centralisation, are in operation in many large railway stations, including Munich, Danzig, Dresden, and Berlin.

Their manufacture of measuring instruments, ammeters, voltmeters, wattmeters, etc., was on a very large scale, also the manufacture of complete switch-boards. Their high-tension switch panels are usually made of white marble, and have a very handsome appearance. Besides the usual ammeters and voltmeters they usually equip their boards with indicating wattmeters, so that the true as well as the apparent watts can be seen at a glance; this is certainly a step in the right direction, particularly where the central station is running motor generators or rotary converters in sub-stations, when the power-factor is often a good way from 100 per cent.

One peculiar type of dynamo design which I have already mentioned we saw under construction, *i.e.*, the type with inside radial pole-pieces and external revolving armature, with the commutator formed on the armature windings. The general design gives one the idea of weakness, and I do not know the peculiar advantages claimed for this type, but one of them may be the possible reduction of expense and material by doing away with the separate commutator and making the armature bars perform the functions of both winding and commutator. I also thought that the type was obsolete, but not only did we see these armatures under construction at the works, but the generators in the new station of the Berlin overhead and underground railway are of this over-hung armature type, but instead of using the bars as commutator, the windings are connected down to a commutator built beside the armature in the normal manner.

In the collection of transformers exhibited I noticed one of 150 K.W. capacity to transform from 500 volts to 20,600 volts, and another of the same capacity to transform from 2,000 volts to 15,000 volts.

On leaving these works one of two courses was open to us, either to drive across to Gross Lichterfelde and inspect Siemens and Halske's experimental high-speed railway, and return to Berlin by the Wannsee electric train, or those interested in what the programme described as weak current plants were invited (by consent of the Imperial Post Office) to inspect telephone exchange No. III. at Berlin.

I chose the former course, and arrived in due time at the experimental road at Gross Lichterfelde, which we were informed was built by Siemens and Halske, to study the application of high-tension currents to traction purposes. The road was opened at the beginning of the year 1899, and has been in operation ever since. The power is supplied as a three-phase current of 10,000 volts. The electric

equipment consists of three overhead wires, which are mounted at the side of the track on poles one above the other. Brackets are fastened to the poles where all wires are flexibly suspended. The lowest wire is about 17 ft. 6 in. above the rail; underneath the wires there is a guard net. The track gauge is 4 ft. 8 in. The locomotive is about 13 feet long with wheels 39 inches in diameter; it is built of iron in the usual way, and has a closed cab. It is provided with both hand and air brake. On the top of the car are three trolley standards, each of which is provided with an insulated current collector or bow, made of aluminium, which presses against the side of the wire by the aid of coil springs. By means of transformers the pressure is reduced from 10,000 volts to 750 volts, at which pressure it is passed through a controller to the two motors, each of which are 30 H.P. normal and 120 H.P. maximum. They drive the axles through single reduction gearing, and can drive the car at a speed of about 37 miles an hour. For speed regulation the controller can make the following connections: Star connection for ordinary running; Delta connection for great pull; one secondary phase open for half-speed. The controller is provided with a magnetic blow-out device.

The track is, I should think, about a mile long. The high-speed car was in active operation, so active, indeed, that it was hard to get a good inspection; it would rush by and come to a standstill, but just when one arrived with a camera it would be off again in the opposite direction. The car appeared to accelerate very fast, but the peculiar purring noise the motors made was rather alarming. The three-phase power was supplied from a little transformer station, a 500-volt direct-current motor driving a three-phase alternator by means of belt. It will be noticed that in this case, and in that of the military three-phase line already mentioned, three overhead wires are used, whereas in the Swiss three-phase railways two overhead wires are generally employed, the rails being used for the third phase. The advantage of the three overhead wires is that they cause no disturbance in any telephone wires they may pass near to.

We then travelled by street car to a railway station on the Wannsee line, tickets being handed to us for our return journey to Berlin, which was accomplished in the experimental electrically-equipped train belonging to this line, which is also the work and design of Messrs Siemens and Halske, and which has been running when required since the 1st of August, 1900. The method of traction employed is continuous current at 750 volts. The train is composed of ten ordinary suburban train cars of the Prussian State railways, the first and last of which cars were adapted and fitted as motor cars. The train empty weighs 193 tons. Each of the six axles of the two motor cars is coupled to a motor. The controlling of the two motor cars is effected from the stand of the car for the time being at the front of the train in such a way that by means of one controller, and a single wire running the full length of the train, the six motors can be simultaneously cut in or out. By means of sliding-shoes the current is collected from a third rail placed at the side of the track. The current required by this train varies from 0 to 1,200 amperes, so batteries are installed at each end of

the line, which is the reason why such a low voltage has been chosen. This train takes its place with the ordinary steam trains, and is a practical experiment on the part of the State railways to find out what advantages electricity has over steam to operate suburban railway traffic.

The visits on the 26th of June were arranged by the Allgemeine Elektricitäts Gesellschaft. An hour's run by steamer brought us to a fine block of buildings which turned out to be the cable works of the "A. E. G."; and close alongside was another high block with two lofty shafts and a coal conveyer, which proved to be the Oberspree Central Station of the Berlin Electricity Supply Company.

The works fire brigade, in a very awesome-looking uniform, lined the route from the landing-stage to the works, and on the landing-stage, to receive us and conduct us round in parties, were the principal officials of the company. Each member was handed a specially printed little pamphlet in book form, describing the works, from which we learnt that the extensive buildings were only erected in 1897, and were designed according to the latest experiences in modern factory building. The works at present extend over about two and a half acres, but there is land for extensions.

Besides the cable works proper, there is a factory for the manufacture of brass, bronze, copper, etc., a factory for the manufacture of rubber and rubber goods, and other insulating materials, and a department for the manufacture of all sorts of Röntgen Ray apparatus, etc. The works are connected by rail with a large goods station, and on the banks of the river there is a crane of five tons capacity operated by three-phase electric motors, so that raw materials can be received, and finished manufactures despatched by either water or rail, at minimum expense in handling. In the yard there was an electric locomotive busily shunting railway trucks, and two electric locomotives for loading and shunting trucks. After passing through the foundry, where fifteen furnaces were at work, we inspected the joinery department, where the cable drums were being made with the help of some special machinery, and then passed on into the rolling mills, where we saw heated copper bars, passed successively through twenty-one different rolls, being squeezed out to greater length and smaller diameter at each roll until it finally emerges as a ring of wire 24 inches in diameter and 300 yards long, the whole operation taking about 40 seconds.

There were two sets of rolls, each being electrically driven, one by a 200-H.P. 500-volt motor, and the other by a 600-H.P. 1,000-volt motor. The output of these works in ten hours was, we were informed, 30 tons of 6 mm. wire. After passing through the rolling process, the wire is cleaned by passing it through baths containing dilute sulphuric acid in order to remove all oxide and other impurities. Next we entered the wire-drawing mills, and saw wire being produced in all the various sizes. Among other modern apparatus the factory is equipped with ten multiple machines on which it is possible to draw the wire through seven holes at the same time. In the fine machines the dies are fitted with diamonds, through which the finer wire is drawn in order to obtain the greatest accuracy; on these machines wire can be drawn down to ·002 inch.

We were then shown the switchboard room. The works have not a power-station of their own, but take their current at 6,000 volts from the Oberspree Power-station of the Berlin Supply Company alongside. In the switchboard room are 16 three-phase transformers which transform the pressure from 6,000 volts to 1,000, 500, or 200 volts as required for the various circuits; their total capacity is 2,600 K.W.

There are also four rotary converters, transforming to 200-volt continuous current; these supply current for the crane motors, locomotives, and arc lamps, and also charge a large battery of accumulators placed in the basement, which would supply the lighting in case of accident to the feeder cables. The lighting of the factory is on the indirect system, inverted arcs, by means of reflectors, throwing the light up to the ceiling, from which it is diffused in a more uniform manner than can be obtained by any direct method.

We next entered the main cable factory, where are located the winding machines which coil the wire from the drums on to suitable bobbins. These bobbins are placed in position on the head of the cable machine, which, on being revolved round, strand up the cable. The stranded cables are then passed through the lapping machines, which put on the insulating material, either paper, rubber, or a combination of jute and paper, in the same manner. The insulated cables are next placed in large receptacles called baskets, and put into a vacuum drying compartment, which is heated by steam coils; when thoroughly dry it is put into the vacuum compound tank, where the paper is impregnated for a certain time, and after this it is passed into the lead-press, and is lead cased. The lead is squeezed on under a pressure of from 3,000 to 5,000 pounds, the cables are then wound on drums and placed under water, and after twenty-four hours' immersion are tested at double their working pressure.

In the test room they can get any pressure up to 50,000 volts alternating. The firm make and use for cable insulation and other purposes a patented compound that they call Stabilit, one great advantage of which for high-voltage cables is its low specific inductive capacity.

I saw two drums of cable each said to contain the same length of cable, and of the same cross-section, one being insulated with paper (whose specific inductive capacity is considered very low) and the other with this material Stabilit, being tested under a pressure of 30,000 volts; the ammeter on the paper cable showed that it was taking (presumably a capacity current of) ·014 amp., but the Stabilit cable was absorbing only ·01 amp. When tested, most of the cable is taken to the armouring machines, where steel wire is stranded on, with the usual finishing coatings of compound and whitewash.

As far as I could make out, the most generally adopted method of laying cable in Germany is to place armoured cable direct into a trench dug in the ground, which system is, I think, in Great Britain being largely displaced by the draw-in or the so-called solid system.

We then inspected the machines for insulating the smaller-sized wires, and for constructing the air-space telephone cables, these cables being made with as many as 306 pairs of wires. There are 100 of these telephone cable machines in the works.

We then passed through the boiler-house, which contains four Babcock and Wilcox, and two Steinmuller boilers; the steam generated being used exclusively for drying, vulcanising, and heating purposes. There was also in the boiler-house a Riedler express pump which was driven by a 15 H.P. three-phase motor. The pump running at 180 revolutions could deliver 24,000 gallons of water per hour; it can also in case of fire, deliver water to the hydrants throughout the building at 90 lbs. pressure. We then passed to the rubber factory and saw rubber in every stage of manufacture, from the crude balls of rubber to the finished vulcanised article; it was interesting to notice the difference in appearance of the crude rubber, as received from the various producing countries. Then there was a department for the manufacture of micanite; the thin mica sheets are stuck together by means of shellac, afterwards being moulded under pressure to the required shape and dried. Next came the braiding shops, where there were 350 machines at work. The noise can be better imagined than described; the ingenuity displayed in the mechanical movements of these machines is always most interesting, although often hard to follow.

Throughout the entire works the machines are driven either singly or in groups by electric motors. The absence of shafting, besides meaning a saving in power and improving the appearance of the works, is most important where the indirect system of lighting is employed, as the heavy shadows caused by shafting and belting are done away with.

We then adjourned to the Casino for lunch, where a certain amount of gratifying speechmaking was got through. Herr Rathenau, the president of the A. E. G. Company, in his speech made some very complimentary remarks about the original work done by many of the English engineers to the advancement of the Electrical Engineering industry.

I should like to mention a few facts about this Casino. It is a splendid building erected for the convenience of, and to supply the wants of, the 3,000 people connected with the works. It has four large halls with accommodation for 1,600 people; in the principal hall of the Casino where we lunched, and which had been most tastefully decorated, there are held weekly lectures of a scientific and instructive nature by the employés of the works, which are attended with great interest by the workmen and workwomen. The ground-floor contained bath-rooms, a surgeon's room, etc. Finally we were informed that everything was done as regards care for the workmen's welfare, in order to do justice to the requirements of modern times. There is also in connection a convalescent home, favourably situated in the woods, which will accommodate 200 invalids.

After lunch we were shown some high-tension discharges and other phenomena, with pressures ranging up to 50,000 volts.

This minute examination of the cable works had left us but little time to inspect the Oberspree Power-station of the Berlin supply station. This station is a magnificent sight at the present time, and will be still more so when it has received the full complement of machinery for which it has been designed, which I understand will total up to the enormous amount of 54,000 H.P.

There are installed at the present time three 3,000-K.W. three-phase

alternators generating at 6,000 volts; these are similar to the sets installed in the Moabit station, being directly connected to the crank shaft and placed between the two lines of cylinders of a horizontal triple-expansion four-cylinder engine. There are also two horizontal engines driving 1,000-K.W. alternators, and two very striking-looking vertical engines, which each drive two 600-K.W. inductor alternators, one set being coupled on each side of the engine.

After finishing our inspection we again embarked on our steamer which took us to Treptow, and on landing we walked through the tunnel of an electric railway under the Spree, after which a short railway journey brought us to the Dynamo and Motor Works of the A. E. G. Company. It was very pleasant to notice how, in every way our hosts tried to show us that we were welcome, and that our visit was looked forward to.

Before entering the works we were much interested with one of the bogey-trucks of the A. E. G. high-speed car.

The main difference between the high-speed systems of the Allgemeine Elektricitäts Gesellschaft and of the Siemens and Halske firms is, that while the latter employ 10,000 volts on the trolley and reduce this by transformers on the car to 2,000 volts for the motors, the A. E. G. Co. intend using 12,000 volts on the trolley, reducing this on the car to 400 volts, thus employing a low voltage motor; but at the same time this firm state that ultimately for long-distance work it may turn out to be better to send out the current at a pressure of 50,000 volts, and transform this at various sub-stations along the line to 3,000 volts, feeding the trolley-wire at this pressure, which the motors on the car would be designed for. This system, while still being a high-pressure one, would do away with the necessity of carrying transformers on the train, which would mean a great saving in many ways.

The "A. E. G." car has been described by Herr Lasche in his paper read before the Institution at the time of the Glasgow Congress.[1]

On entering the factory we found that much of the work was carried out in one large bay, which was covered by a roof on iron lattice girders. The advantage of this appeared to be twofold: first, by the aid of overhead travelling-cranes, machines, when finished in one department, can be easily moved to another; and secondly, supervision is easier, and idling harder, than where walls intervene between the shops. The tools throughout the works were operated by electric motors, any tool of moderate or large size being operated by its own motor. Around the walls of this big shop ran a gallery, occupied mostly by small lathes and other tools.

There appeared to be plenty of work on hand, many of the machines being large three-phase alternators. The work appeared to be very carefully done; for instance, after the core disc stampings were built up into a complete armature, the stampings appeared so accurately got out that the sides of the slot or channel left for the winding appeared to be perfectly true; but nevertheless I noticed that, in order to have a perfectly smooth bed for the coil, it was carefully filed up by hand.

[1] See this Journal, 1901, Vol. 31, p. 24.

We saw also a new departure in the design of large machines, which I believe the A. E. G. have patented, the novelty being in the way the frame was stiffened. The ordinary plan in constructing, say the stationary armature of an alternator, is, after building up the core discs, to bolt them in a cast-iron ring frame, which gives the necessary strength and rigidity to the whole structure; but the A. E. G., in this new plan, are simply clamping the core discs up in a couple of rings, or a frame, of very light structure, and obtaining the required stiffness by means of a system of struts and tie-rods on the same plan as a roof principal is designed. The advantages claimed are lightness, cheapness, and better ventilation.

The firm appeared also to have a big output in standard 500-volt tramway motors and in controllers, and it has struck me as strange that considering the large amount of tramway material these German firms have turned out into satisfactory operation in their own country, that they have not had a bigger share of British patronage, the bulk of the contracts up to the present having fallen to American firms.

After spending about an hour and a half in walking round this factory, we were taken through the tunnel of the underground railway to the same firm's apparatus factory at Acker Strasse.

In this apparatus factory the A. E. G. Co., like the Siemens and Halske firm, seem to manufacture everything electrical except cables and dynamos. They have particularly large departments for the manufacture of arc-lamps, ammeters, voltmeters, and watt-hour meters.

We saw a lot of interesting stamping-machines for producing quickly and accurately, small parts for lampholders, switches, etc. In some of the shops for smaller work, women were working the lathes, drilling-machines, stamps, etc., and looked very happy and interested in their work.

In the evening the two firms, Siemens and Halske and the A. E. G. Co., entertained us at dinner, in which very cordial toasts were proposed on both sides.

On Thursday morning we inspected the "Berlin Electrical Elevated and Underground Railway," which is being constructed by Messrs. Siemens and Halske. We first entered a piece of the finished tunnel or covered subway, which is laid with two lines of track. The line, which runs from the centre part of Berlin out towards the suburbs, is, in the busy part of the town, laid underground, not by deep tunnelling, as in the Central London Railway, but by digging a cutting in the centre of the road: the course it follows being under roads which are very wide. The excavating appeared to be a very simple matter, the subsoil being a fine sand. A retaining wall is built up on each side of the cutting and closed in with a roof strong enough to carry the road traffic. Getting further out towards the outskirts of the town, the railway leaves its subterranean passage and becomes an overhead railway, carried on a lattice girder construction, the supporting columns at the end of the spans being built up of granite, the whole arrangement forming a very elegant structure.

After looking through the partially erected power-station, we inspected what I think they called the junction triangle; here the up

and the down track curve both to the right and left, making connections with a line running at right angles to them, at this point. The original part of the design is that there are no level crossings; this is achieved by letting one track drop in level, cross under the track which in ordinary practice it would intersect at the same level, and then rise again and make connection with the proper track. The object of this very complicated looking construction is, of course, to avoid the possibility of accidents which always exists at level crossings.

In the afternoon we visited the Berlin Technical High School. There were alternative visits to Messrs. Ludwig Loewe and to the Union Elektricitäts Gesellschaft, but I chose the former course.

The Technical High School is situated in a sort of public park at Charlottenburg. We were conducted through the various lecture-rooms, laboratories, library, testing rooms, etc., by Professor Dr. Slaby, Principal of the School, and an inventor of a workable system of wireless telegraphy which is being adopted to a certain extent in Germany. I was much pleased with what I saw, especially with the way in which the laboratories were equipped. In the large electrical testing laboratory the floor was designed so that machines could be bolted down where convenient, while handy little trestle cranes, supplied with chain blocks and mounted on wheels, were supplied, so that the smaller dynamos, motors, etc., could be easily moved about.

The machines that the students were experimenting with were not broken-down ancients, but small modern machines of all classes, gas engine sets, etc. The engine-room of the mechanical engineering department was well worth seeing. One of the most interesting specimens of experimental machinery was a 150 B.H.P triple-expansion engine, the arrangement of the cylinders being very peculiar: the high and the intermediate pressure cylinders were arranged in tandem horizontally, the low pressure cylinder being arranged vertically, but it acted on the same crank as the horizontal cylinders. The engine was direct-coupled to a multipolar dynamo, and was provided with a condenser, superheater, etc., and also with the most perfect experimental appliances. It was supplied as well with a second crank on the main shaft, complete with guides, guide rod, extension frame, etc., so that compressors or pumps could be easily attached for experimental purposes.

When we were there, Professor Josse had attached to this engine crank a fourth cylinder, and on this he had made nearly all the experiments about his sulphur dioxide waste-heat engine, the principle of which appears to be as follows: Instead of the surface condenser, as supplied to an ordinary engine, being cooled by water in the usual way, it is cooled by liquid sulphur dioxide; the temperature of the condenser is high enough to vapourise this liquid and raise it to a considerable pressure, up to 120 to 140 lbs.; this vapour is then admitted to an auxiliary cylinder, by suitable valves, and after passing through this and doing work it is liquified again in a second condenser, by means of cold water, the same liquid sulphur dioxide being used to perform the same cycle over and over again.

In his experiments at the Technical High School, Professor Josse

was able to get a further amount of work from his waste-heat engine of 34·2 per cent. of the steam engine. The total steam consumption in this 200 H.P. engine being under these conditions only 8·34 lbs. of steam per I.H.P., he very proudly compares this with the steam consumption of the new 3,000 H.P. engines at the Luisenstrasse Central Station, which with the same amount of super-heat use 9·58 lbs. of steam per I.H.P.

With our visit to the Technical High School the first part of the German tour ended, members of Group A. returning to London either that evening or first thing in the morning.

Dresden.

One of the principal reasons of the visit to Dresden was to meet the German Society of Electrical Manufacturers, who were holding a convention in this city.

On the Friday afternoon the members of the Institution made very interesting visits, one being described as the "Heat Transmission and Electricity Works of the State." There was a certain amount of speculation as to what the particular duties of this State transmission would be, but what we found was a power-station of good size, with a big array of water-tube boilers, the station being employed to light and heat buildings owned by the State in Dresden. I am sorry to say I did not get as much information about this station as I should like to have, as our guide spoke German only. I learnt, however, that the same boilers were used both for heating purposes and for running the electric lighting sets; when used for the former purpose, the steam pressure was kept at 90 lbs., but for power purposes it was raised to 120 lbs. The steam was super-heated to from 20° to 140° C. The pipes carrying the steam to the various buildings are placed in a subway, being supported on a ball-bearing arrangement or bracket, which allows the pipes to adjust themselves easily for expansion. The effect if you gave one of these pipes a push was very strange, as, owing to its great length and the almost frictionless supports, the pipe kept on swinging for some time like a heavy rope. They had some automatic arrangement which gave them notice in case of a burst anywhere along the subway! The steam, after doing its work, was returning to the station as water, being apparently completely condensed in the return pipe. The lighting system was an ordinary three-wire one, a large battery being also employed.

We next proceeded to the City Lighting and Power Station. Although practically in one building, the Dresden Lighting Plant and Power Plant are kept quite distinct, being in two similar bays placed side by side.

In the bay devoted to the lighting we found a row of eight alternating sets, and although of different makers, the general appearance was very symmetrical. As in a great many of the German stations which we visited, the engines were compound tandem engines acting on a single crank, the valves in all cases being of the Corliss type. Considering the amount one hears of the necessity of a multiplicity of cranks,

if an even-turning movement is required, I was surprised to see in Germany so many single-crank engines driving alternators.

The larger sets in this station were of 1,000 K.W. capacity, the alternators being by the Helios Company; the pressure is 2,200 volts. The smaller sets about 500 kilowatts were by the Lahmeyer Company; the engines in each case ran at 85 revolutions. In this station they never synchronise an alternator running light, with one on the load; the incoming machine being run on an artificial load, then paralleled, and the artificial load taken off.

On entering the tramway power-station we found it in appearance very similar to the one we had just left, the same type of compound single-crank horizontal engines running at 85 revolutions, but direct-coupled to continuous-current machines, each with an output of 1,570 amperes at 520 volts. They were splendid-looking machines, with narrow ring-wound armatures; the field magnets, which contained fourteen pairs of poles, were of great diameter. The switchboard, besides the machine panels, had 23 feeder panels, each of which, besides the usual circuit-breaker, switch, and ammeter, was supplied also with a wattmeter.

Our visit to Dresden finished, the next move was to Nürnberg, the Institution having been invited by the celebrated firm of Schuckert to inspect their works which are situated in this city.

I did not go down to Nürnberg, so cannot tell you what there was to be seen there, but I met the party again in Frankfort on the following Wednesday.

Frankfort.

In Frankfort our hosts were the Elektricitäts Actien Gesellschaft, who were known formerly as Lahmeyer & Co. Although neither as large in output nor in dimensions as many we had already seen, still I think I enjoyed our visit to these works almost more than to any of the others. We were shown round by Dr. Epstein, the chief technical adviser of the firm, who was most courteous and obliging in giving a full explanation of everything we saw.

The way the business of this firm has grown in ten years may be estimated from the following figures:—

In 1891 their workmen numbered	5,	and the staff	22
" 1896 " " "	320	" " "	107
" 1901 " " "	2,100	" " "	756

This firm devote their entire energies to the production of dynamos, motors, transformers, and controlling devices; they also put together switchboards, but they do not manufacture the instruments.

The machine tools and shafting in the shops are driven electrically, the works having their own generating station, supplying both a three-phase alternating current and also a continuous current. All the machine tools that run at practically constant speed are driven by three-phase motors, while those in which it is necessary to vary the speed over a wide range are operated by direct-current motors.

As far as I could make out, this firm do not fall in line with the trend

of the present-day workshop practice of standardising everything, but appear to prefer to lay themselves out for large work, and to design a machine exactly to fulfil requirements instead of fulfilling their orders from the nearest thing they may have in stock. I noticed a good many of the machinists studying blue prints for dimensions, which seems to bear this out, as men who are employed turning up parts for stock machines usually work to gauge.

Most of the large alternating machines under construction seemed to be for 10,000 volts.

We entered the works through an archway composed of the half-field magnet frames of machines intended to work at this voltage. The amount of care bestowed on the work appeared to be very great. For instance, in their continuous-current armatures they use former-wound coils embedded in parallel slots in the armature-core; this armature-core is not made up of discs with the slot stamped in them, but of circular core discs, the slot being afterwards milled out by a vertical milling machine, so as to get a perfectly smooth slot. This is also the shape of slot employed by most firms for alternating machines, but the Lahmeyer Company think they get a better design for alternators by using a deeper slot half bridged across with iron. This shape of slot makes it impossible to use a former-wound coil, so the whole of the armature-winding has to be wound on the machine by hand. This appeared to be a very slow and expensive method, the lapping of the end connections alone, after the winding was on, being a very laborious business.

The transformers this firm build are very curious in appearance, as they are supplied without a case, neither oil nor yet air blast cooling being necessary.

We were shown some large motors, designed to run pumps at an abnormally low speed; also a very neat controller for operating crane motors—there was only one vertical handle or lever, which operated the control for both motors. If this lever is moved to right or left across the building, the traversing motor was started in the same direction; but if the lever was pushed towards, either up or down the room, the longitudinal traverse motor was started in the same direction. The lever could, however, be moved diagonally, in which case both motors were started, so that, practically speaking, the load on the crane always moved in the same direction as that in which this lever was directed.

In the evening a dinner was given in our honour by the Elektrotechnische Gesellschaft of Frankfort, in the beautiful Palm Gardens.

Next morning early I had a run round the Frankfort lighting station. Here again I found a line of large single-crank Corliss engines. The alternators were by Brown, Boveri & Co. In this station, by means of a bell and contact system, they get the engine cranks, so to speak, in phase, as well as the alternators. Extensions were going on.

The city tramcars are run from this station with the help of motor-generator sets in sub-stations. I was in one of the largest of these. It was placed underground in the centre of the city. There were three sets; each of them must have been about six or seven hundred

kilowatts. There was also a large storage battery. I think batteries are more popular on the Continent, in connection with traction schemes, than they are in the British Isles.

Thursday, July 4th, was really the last day of the trip. In the morning we were taken by the Elektricitäts Actien Gesellschaft to Wiesbaden to see a combined traction and lighting plant put down by them for the municipal authorities. This installation is interesting from two points of view. The Wiesbaden central station was one of the first to use three-phase currents for lighting purposes, and it may interest some present to know that the results have been most satisfactory. The second interesting point is the curious arrangement of engine and generating sets. The engines are single-crank horizontal, tandem compound engines, with Corliss valves; but coupled to each engine shaft is a three-phase alternator generating current at 2,400 volts, a direct-current alternator generating current at 500 volts, and also an exciter. The engine is large enough to drive only one of these two machines when the latter is fully loaded, the larger sets consisting of an engine of from 900 to 1,200 B.H.P. coupled to a three-phase alternator of 800 kilowatts and to a direct-current generator of 800 kilowatts capacity. By this arrangement it is claimed that in a combined traction and lighting station the engines can more easily be kept at full load than where the engine is coupled to one class of generator only. Another interesting feature was the manner in which the transformers were housed. Instead of being buried in cramped underground chambers, they are installed in iron kiosks, which stand in positions convenient for distribution, and are no eyesore in the streets. The sides are arranged on hinges, and can be opened back as doors, when the switches, fuses, etc., are easily accessible from the street without entering the chamber itself. There is much to be said for such an arrangement on the score of safety, although the manipulation of switches and fuses in public might, under certain conditions, be rather embarrassing.

On the afternoon of this day the same firm generously conducted us to Homburg, where we visited the electricity works, which is a combined lighting and traction station with the same arrangement of engine and dynamo sets, the only difference being that vertical engines are employed, which are each connected to two direct-current generators, one for traction and one for lighting at a different voltage.

The party then proceeded by a new electric railway to Saalburg and inspected some very interesting Roman remains, returning in the evening to Homburg, where our hosts entertained us at dinner.

On the following day most of the party travelled home by way of the Rhine, which finished up pleasantly what was admitted, I think, by all who took part in it, to have been a most successful and enjoyable trip.

Mr. J. W. Towle thought the members would wish they had been of the visiting party to Germany. The practice of bringing tools to the work instead of taking the work to the tools was largely followed, and was undoubtedly the right thing. With regard to the machines with Mr. Towle.

Mr. Towle. the radial pole-pieces, Professor Forbes told us when in Dublin that the dynamos at Niagara had a somewhat similar construction, and said that one of the advantages was the counteracting of the centrifugal force by the magnetic pull. He also asked Mr. Sheardown to describe the methods of insulating the 10,000-volt line.

Dr. Trouton. Dr. F. T. TROUTON asked if Mr. Sheardown had been able to observe whether the amount of technical education in Germany had had any connection with the enormous development of work which has lately taken place in that country. This aspect of the question was of great interest at the moment to us in this country, when so much was being talked about with regard to education in Ireland.

Mr. Ruddle. Mr. M. RUDDLE thought the generation of 1 k.w. by 1½ lbs. of coal was only done on a very special test. So far as he had seen, and he had been all over the ground described in the paper, the almost universal practice in Germany appeared to use single-crank engines. The standard of steady voltage was much below what would be tolerated here, and he instanced a case where the pressure, at first 120, fell to 95 and then settled to 105, due to the switching in of motors on the premises of a large consumer.

Professor Barrett. Prof. W. F. BARRETT expressed the thanks of the meeting to the author for the carefully compiled and instructive paper to which they had listened with much interest. The rapid growth in German industrial enterprise synchronised, and was doubtless closely connected with, the remarkable development in higher technical education which has been going on in Germany under the fostering care of the State. There is no technical college in the whole of our United Kingdom comparable with the splendid school at Charlottenburg to which the author of the paper had alluded. He hoped our own Government would realise the importance of this question ere it was too late.

Mr. Sheardown. Mr. P. S. SHEARDOWN replied that Mr. Towle's remarks about the modern practice in shops of bringing the tools to the work instead of the work to the tools was quite borne out by what he saw. One reason for this was, of course, that as the size of machines increases, it becomes harder and more expensive to move the various parts from tool to tool. A second reason was, that by the use of electrically driven tools it becomes much easier to bring the tool to the work than in days when the belts were the only means of transmission.

With regard to the insulation of an overhead line to work at 10,000 volts there did not seem to be much difficulty, and it was an easier problem to provide suitable porcelain insulators for a straight through line, in which the current is collected from the side, than with the conditions that have to be fulfilled in street railway practice.

With regard to Dr. Trouton's inquiry, he could not say that anything he saw or heard would put him in a position to express an opinion as to how much Germany is benefiting from her Technical Instruction System, but it did strike him that the lesson in discipline learnt by the three years' army service made the maintenance of proper control and order in the shops easier, and he thought in the long run the conscription system in Germany must be more of an advantage than a disadvantage.

Mr. Sheardown.

Professor Barrett thought there was a more progressive spirit about the German public than we find in Great Britain, and he believed this to be to a certain extent true. We had a habit of talking about "the good old times" with the result that one notices that many public committees approach questions involving radical change with an evident bias towards letting things remain as they are.

BIRMINGHAM LOCAL SECTION.

NOTE ON ALTERNATE-CURRENT DIAGRAMS.

By W. E. SUMPNER, D.Sc., Member.

(*Paper read at Meeting of Section, December* 11, 1901.)

Alternate-current quantities can be represented by polygonal figures exactly as if they were forces. The length of the line represents the magnitude of the corresponding quantity, while its inclination denotes the phase. The phase angle between two lines is such that the cosine of the angle multiplied by the product of the lengths of the lines is equal to the average value of the product of the two quantities represented by the lines. The treatment of mechanical problems is often simplified by splitting up the forces concerned into components along perpendicular axes, adding the components, and compounding to find the resultant. Similarly many alternate-current problems can be most easily dealt with by the separate consideration of the rectangular components of the quantities met with.

This process has been long known, and has been much used, in cases where it can be assumed that the currents and potentials vary according to a simple sine law. It has been proved by the present writer to be also perfectly accurate whatever the law of variation of the current. [See "The Vector Properties of Alternating Currents," *Proc. Roy. Soc.*, 1897, vol. 61, p. 455.] The proof rests upon one fundamental proposition which was established in the paper referred to. A particularly simple proof of it recently found seems worthy of notice.

The proposition in ordinary language implies that the power-factor of an alternate-current circuit must be less than unity except for perfectly non-inductive conductors. More generally it can be stated thus :—

If x and y are two quantities varying with time in any way whatever (excepting the special case in which x is a constant multiple of y), the average value of the product xy is necessarily less than X Y where—

X^2 is the mean value of x^2,

and—

Y^2 is the mean value of y^2.

To prove this, consider—

$$(Xy - Yx)^2.$$

This quantity being a square is necessarily positive. Thus—

$$X^2 y^2 + Y^2 x^2 > 2\,xy\,X\,Y.$$

This being true at every instant, must be true also for the mean. Now X and Y do not vary since they are averages,

also—

$$\text{mean } y^2 = Y^2 \qquad \text{by definition,}$$

and—

$$\text{mean } x^2 = X^2 \qquad \text{by definition.}$$

Represent the mean of xy by $\overline{xy}$.
Substitute and we get—

$$2\,X^2Y^2 > 2\,\overline{xy}\,XY,$$

or

$$XY > \overline{xy}.$$

Thus if x is the voltage applied to a conductor and y the current through it, the product XY of the volts and amperes, as read by alternating-current instruments, exceeds the mean value of xy. In other words, the "power-factor" is less than unity. The only exception is when—

$$(X\,y - Y\,x)^2$$

is zero at every instant, or when—

$$\frac{x}{y} = \frac{X}{Y} = \text{constant}$$

for every instant. In this special case the power-factor is unity.

Even if the current does not alternate, but merely varies in some manner different from the voltage, the power-factor must be less than 1.

The proposition above stated is of very general application. It is not confined to the case of the voltage and current on a particular conductor. It is true of any two variable quantities. It shows that there is always some factor f, less than unity, for which—

$$\overline{xy} = f \times X \times Y,$$

and f may conveniently be called the "product-factor" of the quantities x and y. The importance of the result is due to the fact that it really forms the basis of the method of representing alternating-current quantities by triangle diagrams, as it is possible to deduce from it that this well-known method is accurate however great the variations from the sine law may be.

It may be noticed incidentally that the ordinary idea that it is possible to bring the power-factor of an inductive current up to unity by the use of compensators is erroneous. All that can be done is to raise the power-factor to a maximum value less than unity. The adjectives lagging and leading as applied to alternating currents, are convenient but inaccurate. A current may be lagging when it is near zero, and leading in the neighbourhood of its maximum.

THE TESTING OF MOTOR LOSSES.

By W. E. SUMPNER, D.Sc., Member.

In the case of direct-current machines the well-known Hopkinson method is admirably adapted to determine the temperature after a long run, and the losses under various conditions of load. The method can be applied to alternators, whether single-phase or multi-phase, when two similar machines are available. In the case of single-phase dynamos only one machine is necessary, since any multipolar alternator can be regarded as a number of similar machines coupled in series. [See this Journal, 1893, vol. 22, p. 116: W. M. Mordey on "Testing and Working Alternators."]

For the separation of the losses in direct-current dynamos and motors the best known method is that of Kapp and Housman. This method requires only the simplest possible instruments, and is well suited for workshop testing. It has an advantage over the Hopkinson method in that it only requires the one machine under test. The method may be extended to alternating-current machinery, but all the simplicity is lost. The instruments required are not usually available in works, and, especially for the case of polyphase machines, the testing becomes complicated.

A better method for alternators is to run the machine at various speeds and excitations by a separately excited direct-current motor, measure the power supplied electrically to the latter, and allow for the losses.

But a difficulty arises in applying this method to machines having heavy revolving parts. Suppose a current of 40 amperes in the motor is just sufficient to balance the losses and maintain constant speed, and let the current increase to 44 amperes. The accelerating current will be 4 amperes, exerting a torque one-tenth of that due to friction, and the machine will speed up at one-tenth of the rate at which it would slow down on open circuit. Now with heavy machines this drop of speed may occur very slowly, at a rate of less than 10 per cent. per minute. In such a case the motor current could be anything from 36 to 44 amperes without the speed changing more than one per cent. per minute, and with ordinary speed indicators the speed would seem constant for any current between those limits.

It seems desirable in such cases to use some method in which the kinetic energy of the running machine forms the source of power, and to deduce from the way in which the machine slows down under the retarding torque due to frictional and other losses, the magnitudes of these losses. The idea of utilising the inertia of the running machines for such a purpose has been previously suggested by Ashworth, Routin, and others, but the methods recommended have been suitable rather for the laboratory than for the workshop. A number of references, and a good account of several of these methods will be found in articles by Professor Hay printed in the *Electrical Review* for August, 1900.

Acceleration methods of this kind will be good or bad according as

the instrumental methods used for making the observations are or are not sufficiently accurate and simple to apply. In each of the three methods below the process suggested for making the measurements possesses some advantages over others previously published.

The first method, which has been successfully used for several years past in the classes of the Birmingham Technical School, can be recommended on account of its simplicity. The only apparatus required are an ordinary watch, a good speed indicator, and some means of applying to the machine a small measured retarding torque either mechanically or electrically.

Observe (by counting the number of ticks of a watch) the time taken for the machine to slow down between two given speeds R_1 and R_2 as read by the speed indicator. The loss of kinetic energy of the revolving mass is—

$$a(R_1^2 - R_2^2)$$

where a is a constant depending on the moment of inertia of the rotor.

If T is the retarding torque due to the losses in the machine, T varies very slowly with the speed, and can be regarded as constant during a change of about 10 per cent. in the speed R. If T is constant, R diminishes uniformly, so that the work done in the interval t is—

$$2\pi T \frac{R_1 + R_2}{2} t$$

whence—

$$T t \pi (R_1 + R_2) = a(R_1^2 - R_2^2),$$

or—

$$T t = \frac{a}{\pi}(R_1 - R_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If, therefore, in different experiments, we alter T but keep R_1 and R_2 the same, the value of T is inversely proportional to the corresponding value of t. If by increasing T by a known mechanical torque T_0 the value of t is altered to t'.

$$T t = (T + T_0) t',$$

or—

$$T = T_0 \frac{t'}{t - t'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and—

$$T t = T_0 \frac{t t'}{t - t'} = \frac{a}{\pi}\left(R_1 - R_2\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which determines a, and hence the kinetic energy at speed R.

T may now be altered by varying the excitation of the machine, and in other ways, so that the torque due to hysteresis and eddy-currents can be separated from that due to friction. Moreover, by use of equation (3) the torque at different speeds can be determined.

If the constant in the equations is determined electrically by applying a torque due to a current generated by the machine,

let W = the watts wasted due to the machine losses,

and let w = the watts generated by the machine in the calibration test,

we then have—

$$W t = (W + w) t' = a (R_1^2 - R_2^2),$$

or—

$$W = w \frac{t'}{t - t'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and—

$$W t = w \frac{t t'}{t - t'} = a (R_1^2 - R_2^2),$$

and similar remarks apply.

This method is capable of yielding good results even with small machines when a good speed-indicator is available. With very little practice the method of counting the time interval by the number of ticks of a watch becomes more accurate than by use of a stop-watch, so that an ordinary watch is all that is necessary. The limit of accuracy is determined by the speed-indicator. A good tachometer will be found accurate enough in most cases.

The form of equation (3) shows that to get a good result t' should be about half of t. To read t' accurately it should not be less than $2\frac{1}{2}$ seconds, or 10 quarter-second ticks of the watch, so that t should not be less than 5 seconds, and thus $R_1 - R_2$ in (3) should not be less than the change of speed in this time. Now small machines take about 30 seconds to slow down from full speed to rest, and the change in R in 5 seconds will be nearly 20 per cent. With large machines the time of slowing down may exceed 30 minutes, or 1,800 seconds, so that the time intervals t and t' for a change of speed easily observed on the tachometer will be considerable, and can be readily measured. In all cases the method is easily applicable, when the speed-indicator is at all reliable.

An entirely different method of observing the change of speed can be applied wherever there are large alternators working in parallel. The synchronising apparatus can be employed as the speed-indicator by making use of the principle of beats. If the machines are running in synchronism, and power be shut off from one machine and its armature circuit opened, the synchronising apparatus will show more and more rapid beats. If it is possible to count the number n of beats occurring in a time t from the moment of opening the armature circuit, it can be shown that—

$$\frac{T t^2}{n}$$

is a constant quantity for any particular machine (T being the retarding torque caused by the losses).

In the short time t the number of periods which occur will be, for dynamos giving p periods per revolution—

$$p R_1 t \text{ for the first alternator,}$$

and—

$$p (R_1 + R_2) \frac{t}{2} \text{ for the second alternator.}$$

These quantities will differ by n,

$$\therefore \; p R_1 t = n + p (R_1 + R_2) \frac{t}{2}$$

or—

$$2n = p t (R_1 - R_2).$$

If the frequency of the current is $f = p R_1$

$$2n = f t \frac{R_1 - R_2}{R_1} \qquad (5)$$

But by (3)—

$$T t = \frac{a}{\pi} (R_1 - R_2)$$

$$\therefore \; \frac{T t}{2n} = \frac{a R_1}{\pi f t}$$

or—

$$\frac{T t^2}{n} = \frac{2 a R}{\pi f} = \frac{2a}{\pi p} \qquad (6)$$

Thus T is proportional to the number of beats occurring in a given time, or inversely proportional to the square of the time taken for a given number of beats. If both t and n are observed—

$$\frac{T t_1^2}{n_1} = \frac{T' t_2^2}{n_2}$$

and if in the second experiment $T' = T + T_o$

$$T = T_o \frac{\frac{t_2^2}{n_2}}{\frac{t_1^2}{n_1} - \frac{t_2^2}{n_2}} \qquad (7)$$

The number of beats occurring in a time t is proportional to t^2. Whether or not these are too quick to count will depend on the values in equation (5).

$\frac{R_1 - R_2}{R_1}$ is the fractional drop of speed in time t.

Supposing a is the fractional drop of speed per second, then—

$$\frac{R_1 - R_2}{R_1} = a t$$

and—

$$2n = a f t^2 \qquad (8)$$

Thus if the frequency of the current is 100 per second, and the speed falls 1 per cent. per second $n = \frac{1}{2} t^2$, or in 4 seconds there will be 8 beats; and the method becomes rather too sensitive for easy measurement, as the beats will occur rapidly. But with large machines, and the moderate frequencies now common, the beats will not occur with

inconvenient rapidity. Thus for a machine taking 10 minutes to slow down from full speed to rest, and for a current frequency of 50 periods the time for 4 beats will be about 10 seconds, and can easily be observed.

If the machine tested is a direct-current shunt machine, or an alternator provided with an exciter on the same shaft, or any machine which is run up to speed by means of a belted shunt motor, a much better method of measuring the change of speed is available without the use of a speed-indicator at all. The method consists, as indicated in Fig. 1, of using a suitable low-voltage voltmeter to measure the difference between the voltage of the field-magnet coils and the induced E.M.F. in the armature. The field-magnet is permanently connected to constant potential mains, the armature being connected across these mains through a switch and starting resistance, the switch end of the armature being also connected to the corresponding main through a voltmeter provided with a key. When the desired speed is attained the armature switch is opened and the voltmeter key closed. The reading of the voltmeter is a direct measure of the change of speed $(R_1 - R_2)$ in (3). The method then merely consists in observing the time interval taken for the voltmeter to change its deflection between two given values, and formulæ (2) and (4) apply. When this method is applicable the speed readings can be very accurately taken.

The only novelty in the suggestion of using a voltmeter as speed indicator arises from the special way in which it is connected. Instead of joining it up across the armature so as to indicate the total speed of the machine, it is connected so as to measure the difference between the constant voltage corresponding with the normal speed, and the actual voltage due to the reduced speed. It is thus possible to use a sensitive voltmeter capable of indicating by a considerable deflection small changes in speed. This is a great advantage, for in these acceleration methods the time measurements can be much more accurately taken than the speed indications. It is, besides, desirable to make the measurements for a small percentage change in the speed.

To test this method, experiments have been made on one of the three Parker dynamos in the engine room of the Birmingham Technical School. Each dynamo gives at full load an output of 40 units at 110 volts, the speed being 800 revolutions per minute. It is belted to a Tangye gas engine running at 160 revolutions. Both engine and dynamo are provided with heavy fly-wheels. The engine running alone takes 2 minutes to slow down from full speed to rest. When belted to the dynamo, this time is increased to 4 minutes. The time of slowing down of the dynamo alone, on open circuit, is 22 minutes.

The slow acceleration of the machines, owing to the excessive inertia of the revolving parts, was no advantage in the tests, since the time intervals could be measured much more accurately than the angular movement of the pointer of the voltmeter. If the machines had slowed down more rapidly, the use of a lower reading voltmeter would have secured equal precision.

The only instruments needed for the test were a watch, a voltmeter, an ammeter and a common water resistance. It was not found

necessary to alter a single connection between the dynamo and the switchboard. The field coils were permanently excited from the 'bus-bars. The armature had its negative brush permanently connected with the negative bar, and its positive was on open circuit except when connected through the ammeter and water resistance to one of the 'bus-bars (the positive bar for speeding up and the negative for slowing down.)

The voltmeter v was so connected that it read the difference between the voltage V_0 of the 'bus-bars, and V the voltage on the armature of the dynamo under test.

For constant excitation V will measure the speed of the machine, so that the kinetic energy K of the revolving parts will be—

$$K = a V^2 \quad \text{and} \quad K_0 = a V_0^2,$$

where a is some constant and K_0 is the value of K for the speed of the

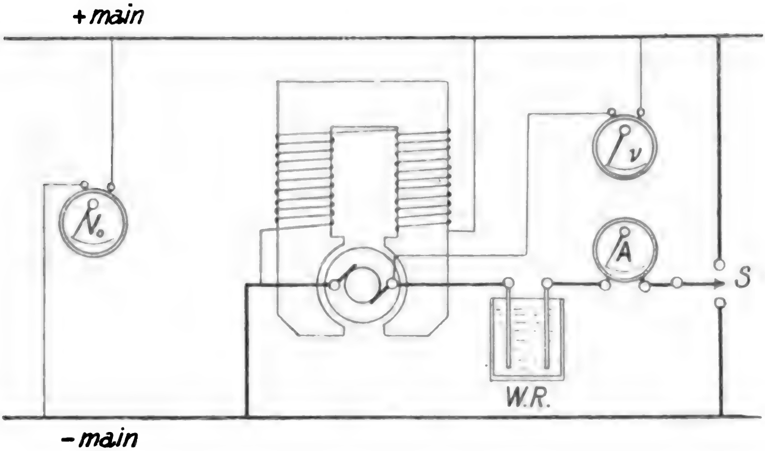


FIG. 1.

machine at which the armature gives $V_0 = 110$ volts. If during a time $t_2 - t_1$ the value of V changes from V_1 to V_2, and the diminution of energy is merely due to a loss of W watts in friction,

$$W(t_2 - t_1) = a(V_1^2 - V_2^2) = \frac{K_0}{V_0^2}(V_1^2 - V_2^2),$$

we may put—

$$W = A_0 \frac{V_1 + V_2}{2},$$

and substituting—

$$A_0 = \frac{2 K_0}{V_0^2} \quad \frac{V_1 - V_2}{t_2 - t_1},$$

where A_0 is that current which, if flowing through the armature so as to oppose the friction, will just balance it and keep the speed constant.

Now—

$$V_1 = V_0 - v_1 \qquad V_2 = V_0 - v_2 \qquad V_1 - V_2 = v_2 - v_1$$

where v_1 and v_2 are the readings of the voltmeter.

Also $\frac{v_2 - v_1}{t_2 - t_1}$ is the rate of change of v per second. Calling this $\dot{v}$, we have—

$$A_0 = \frac{2\,K_0}{V_0^2}\,\dot{v} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

If in addition to the frictional torque there is one due to a current A in the armature, we have, according as A aids or opposes friction—

$$A + A_0 = \frac{2\,K_0}{V_0^2}\,\dot{v},$$

or—

$$A_0 - A = \frac{2\,K_0}{V_0^2}\,\dot{v} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Hence, if we make experiment with different values of A, and observe the corresponding values of $\dot{v}$, the connection between A and $\dot{v}$ will be linear for all speeds for which we can assume A_0 to be constant. This relation will give not only the value of A_0, and hence W the watts wasted in friction, but also K_0 the kinetic energy of the revolving parts at the normal speed.

In a preliminary test of the engine and dynamo running together with the field of the latter not quite fully excited, it was found that v altered from 6 to 27 volts in 55 seconds. Thus $\dot{v}$, or the voltage change per second, is 0·38.

$$\therefore A_0 = \frac{2\,K_0}{110^2} \times {\cdot}38.$$

But with a load current of 51·5 amperes it was found that the rate of loss of voltage was increased to 0·53 volts per second, v changing from 8 to 29·3 volts in 40 seconds.

$$\therefore 51{\cdot}5 + A_0 = {\cdot}53 \times \frac{2\,K_0}{110^2}$$

Whence—

$$\begin{aligned} A_0 &= 130 \text{ amperes.} \\ W &= 14{\cdot}3 \text{ kilowatts.} \\ K_0 &= 2{,}070{,}000 \text{ watt-seconds.} \\ &= 0{\cdot}557 \text{ kilowatt-hours.} \end{aligned}$$

In a more complete test taken with the machine fully excited, and slowing down on open circuit, the following corresponding values of v and t were found :—

$$\begin{aligned} t &= 0, \quad 25, \quad 50 \text{ seconds.} \\ v &= 3, \quad 15{\cdot}5, \quad 27{\cdot}5 \text{ volts.} \end{aligned}$$

Whence it appears that $\dot{v}$ slowly diminishes from 0·50 to 0·48 volts per second.

Taking $\dot{v} = 0{\cdot}49$, we have—

$$A_0 = \frac{2\,K_0}{(110)^2} \times {\cdot}49.$$

The machines were again run up to speed by the engine, the gas from the latter being then shut off. A load current of 52 amperes was taken from the armature. Observations taken over an interval of 30 seconds showed that $\dot{v}$ had been increased to 0·73 volts per second. We then have—

$$52 + A_0 = \frac{2\,K_0}{(110)^2} \times \cdot 73.$$

Whence—

$$A_0 = 106 \text{ amperes.}$$
$$W_0 = 11 \cdot 7 \text{ kilowatts.}$$
$$K_0 = 1{,}310{,}000 \text{ watt-seconds.}$$
$$= 0 \cdot 364 \text{ kilowatt-hours.}$$

The differences between the new values found for W and K and the former ones is satisfactorily accounted for by the difference in the speeds necessary to produce 110 volts under the two conditions of excitation of the field. As the speed does not vary greatly, the frictional torque may be assumed the same in both experiments. The strength of the field is inversely as the values found for A_0, and the speed producing 110 volts varies directly as A_0.

Since K, the kinetic energy, increases as the square of the speed and W as its first power, we must compare—

$$\cdot 364 \text{ with } \cdot 557 \times \left(\frac{106}{130}\right)^2$$

and—

$$11 \cdot 7 \text{ with } 14 \cdot 3 \times \left(\frac{106}{130}\right).$$

The former number works out to be 0·37, and the latter 11·6. The agreement is better than was expected, and is to be regarded as somewhat accidental.

Observations were then made on the dynamo alone. The engine belt was removed, and the dynamo run up to speed by passing through its armature a current taken from the 'bus-bars through the water resistance. When the machine had nearly attained the normal speed, observations were made of the accelerating current A, and the corresponding rate of rise of voltage $\dot{v}$. The armature switch was then opened and the new value of $\dot{v}$ observed.

The following numbers give one set of readings for A = 0 :—

t =	0,	60,	120,	180,	240 seconds.
v =	10	17·5,	25,	32·5,	38·5 volts.

Whence $\dot{v}$ is 7·5 volts per minute, or $\dot{v} = \cdot 125$ volts per second.

The numbers in the table below give simultaneous readings of t, v and the accelerating current A for a period of 2½ minutes.

The numbers given in the last three columns show—

(i.) The decrease in v for successive interval of one minute.
(ii.) The average current during these intervals.
(iii.) The value of $\dot{v}$.

t	v	A	$60\,\dot{v}$	Mean A	$\dot{v}$
0	30·5	56		-	
30	23·8	55	12·0	54·7	·200
60	18·5	53	9·3	50·3	·155
90	14·5	43	6·5	43·3	·108
120	12·0	34	4·0	35·7	·067
150	10·5	30			

After these readings had been taken another set of observations was made on the slowing down of the machine on open circuit. The readings taken were—

$$t = 0, \quad 60, \quad 120, \quad 180 \text{ seconds.}$$
$$v = 10, \quad 18{\cdot}2, \quad 26{\cdot}5, \quad 34{\cdot}7 \text{ volts,}$$

giving $\dot{v} = {\cdot}136$ volts per second.

Tabulating the results for A and $\dot{v}$, we have—

A	$\dot{v}$	
	Obs.	Calc.
0	+ ·125	+ ·131
35·7	— ·067	— ·067
43·3	— ·108	— ·110
50·3	— ·155	— ·149
54·7	— ·200	— ·174
0	+ ·136	+ ·131

The constancy of the value of $\dot{v}$ found in each set of observations for which A = 0 shows that the difference between the first and last values in the above table is due to a real alteration in the frictional resistances during the interval. The values of $\dot{v}$ found for any two values of A are sufficient to determine—

$$A_0, \ W \ \text{and} \ K,$$

since—

$$A_0 - A = \frac{2\,K}{(110)^2} \times \dot{v}.$$

This equation is confirmed by the fact that the values in the above table are found to follow the law—

$$23{\cdot}5 - A = 180\,\dot{v},$$

the values of $\dot{v}$ calculated from this equation being given in the third column in the table. Thus, for the dynamo alone we have—

$$A_0 = 23{\cdot}5 \text{ amperes.}$$
$$W = 2{\cdot}58 \text{ kilowatts.}$$
$$K = 1{,}090{,}000 \text{ watt-seconds.}$$
$$= {\cdot}303 \text{ kilowatt-hours.}$$

For the engine and dynamo together the loss found was—

$$11{\cdot}7 \text{ kilowatts,}$$

or about 9·1 kilowatts for the engine alone. The result was afterwards confirmed by indicating the engine and dynamo running light. The loss found was in satisfactory agreement with that obtained by the electrical method.

It will be seen that if the kinetic energy K_0 at normal speed, for a particular engine and dynamo, is known, a single determination of $\dot{v}$ is sufficient to determine the frictional losses. Equation (9) shows that this loss is—

$$2\,K_0 \frac{\dot{v}}{V_0} \text{ watts,}$$

where V_0 is the voltage on the armature at normal speed. If an accelerating current of A amperes is passed through the armature when $\dot{v}$ is observed, the frictional loss is—

$$2\,K_0 \frac{\dot{v}}{V_0} \pm A\,V_0 \text{ watts,}$$

the + or — sign being chosen according as A opposes or aids friction.

Mr. R. H. Housman: We have to thank Dr. Sumpner for two very instructive and interesting papers. By the first we are relieved from the anxiety that alternating-current diagrams rely on sine curves; and in the second some very interesting and novel methods are used. But in the latter case, I do not think that sufficient credit is given to the original author, Mr. J. Swinburne. The other two methods (Kapp and Housman's) enable us to separate the losses into two parts: those proportional to the speed, and those proportional to the square of the speed. By keeping the excitation constant and altering the voltage on the armature, a diagram of current and E.M.F. can be obtained in which we have a series of points lying on a line. The assumption is that the losses may be divided into two parts—one overcome by a torque proportional to the speed, and the other by a Mr. Housman.

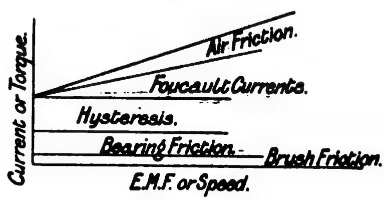


FIG. A.

Mr. Housman.

constant torque, the proportional part being due to Foucault currents, and the constant part to hysteresis and friction.

But the hysteresis may not remain constant; the curve probably slopes upwards. The frictional loss is also assumed to be proportional to the speed, but with good bearings the friction is fluid friction, varying with the square of the speed. The brush friction is, of course, solid friction and constant at all loads. Within the limits we are dealing with, however, the friction may be assumed constant and acting as solid friction, but the air friction has been altogether neglected, and this increases with the square of the speed. The sloping part of the diagram is, therefore, due to the increase of the above losses and to air friction, as well as to Foucault currents.

There is a fairly simple method of distinguishing between these losses by running the machine at various strengths of fields, and since the loss in eddy currents depends only on E.M.F. and not on speed, any increase in the slope of the diagram is due to increase of air friction at the higher speed. The losses due to air friction are considerable, but depend on the shape of the armature and on ventilation.

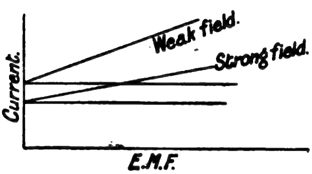


Fig. B.

In taking these diagrams there are a number of precautions to be observed. In the first case, the bearings must have been run long enough for the temperature to become steady and the friction to attain its final value. Again, the commutator must be clean before readings are taken, for the leakage when the commutator is black is so great, that by merely wiping off the black deposit readings can always be decreased.

Dr. Sumpner has drawn attention to the difficulty with machines having very heavy flywheels or armatures, with which the speed will gradually increase; and the final value is only reached after a lapse of several minutes. In cases where the weight is not very excessive, by varying the voltage when the final speed is nearly reached, first decreasing and then increasing, we can get a number of readings of the current and, by taking the mean, get a very near approximation to the truth.

I think that Dr. Sumpner's method of measuring the losses by alteration of kinetic energy is specially good in the case of dynamos connected to gas engines, and the method which he uses to measure the loss of speed is on the whole particularly adapted for this purpose. In the case of alternating machines I think this method is very satisfactory; but this is not the case with small machines where the times are too short, and the ordinary methods are to be preferred. There is a certain amount of complexity due to the mixture of mechanical and electrical units used in the measurements. I think that the method to which the author gives the most prominence, viz., when using engines with heavy flywheels, will be most satisfactory and useful; and the method of applying it to alternators also appears elegant and exact.

Mr. A. M. TAYLOR: I wish to refer to the first paper, on alternating-current diagrams, in which there is this sentence: "The phase angle between two lines is such that the cosine of the angle multiplied by the product of the lengths of the lines is equal to the average value of the product of the two quantities represented by the lines." Dr. Sumpner in his paper proves that if you have two quantities x and y, both varying with time, that the product of the R.M.S. values of these two variables is always greater than the average value of the product of the variables. He deduces from this that whatever the relations of current and pressure with time, X Y cos ϕ correctly gives the watts in the circuit. I submit that the proof, as given, does not warrant this deduction, and to show this I have taken a case where the current lags 50 degrees behind the E.M.F. Of course the assumption is correct for sine curves, and I find it is approximately correct for parabolic curves where $f = 0{\cdot}643$; but if the wave form consist of a series of triangles— Mr. Taylor.

$$X\,Y = {\cdot}682$$
$$\overline{x\,y} = {\cdot}366$$
$$\therefore f = \frac{\overline{x\,y}}{X\,Y} = {\cdot}538,$$

and assuming the wave form to consist of a series of rectangles—

$$X\,Y = 2{\cdot}0$$
$$\overline{xy} = 0{\cdot}89\,;\ \therefore f = \frac{\overline{x\,y}}{X\,Y} = 0{\cdot}445,$$

showing that Dr. Sumpner's "product factor" (f) is not equal to cos ϕ, the value of which is 0·643 for 50° difference of phase.

Dr. SUMPNER: What do you mean by an angle of 50 degrees? Dr. Sumpner.

Mr. TAYLOR: I mean an angle of 50 degrees between the centres of the wave forms representing current and E.M.F. I am afraid that we must not run away with the idea that the watts are given by X Y cos ϕ for every conceivable case, but perhaps I am misunderstanding Dr. Sumpner's conclusions in this respect? Mr. Taylor.

Dr. Sumpner also shows that $X\,Y > xy$ in every conceivable case, but, in the case of separately excited synchronous motors, for a certain excitation we can represent the values of the impressed E.M.F. (O A), the back E.M.F. (O B), the combined ohmic and inductive drop (A B), and the current A C by a Figure C—

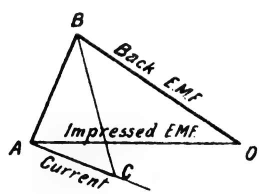


FIG. C.

If now the excitation be increased so that the triangle A B C swings round bringing A C to the other side of O A, then at a particular point in the excitation you must surely have a power-factor of unity, viz., when the line A C coincides with the line O A.

Mr. HENRY LEA: In Dr. Sumpner's paper on the testing of motor losses, I take it that the method he advocates is confined to observations made when the motor is slowing down, and he takes as an instance the machinery which is producing electricity in this building with Mr. Lea.

Mr. Lea.

which I have a practical experience. This machinery consists of three dynamos belted to Tangye gas-engines, both engine and dynamo being provided with flywheels and taking four minutes to slow down from full speed to rest. He deduces from observations taken during the process of slowing down what the total internal losses of the whole plant are. But when slowing down, the frictional losses must be very different from what they are when the dynamo is driven at full load. In the one case you have an initial pressure of 300 lbs. per square inch, and this, owing to the early ignition now used in gas engines, throws a tremendous pressure on the main bearings and big end of connecting-rod without doing much useful work, but merely engaged in producing friction. When slowing down, the initial pressure on the piston is only about 90 lbs. per square inch, and the frictional losses must be very much less than at full load. Owing to the insufficient weight of flywheel on these engines, and the consequent necessity for heavy flywheels on the dynamos, the belt has a series of sudden impulses applied to it causing slipping. But with the test as made on slowing down, the dynamo is driving the engine with constant effort, and the losses will be very different from what they are when the engine is driving the dynamo loaded. These two sources of loss are not taken into account in Dr. Sumpner's calculations, and I think that the results would not

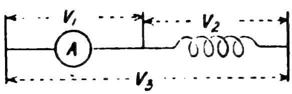


FIG. D.

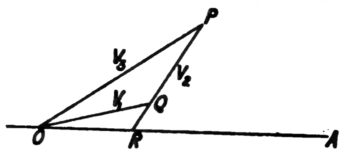


FIG. E.

be correct for tests carried out on machinery such as there is in this building.

Dr. Sumpner.

Dr. W. E. SUMPNER (*in reply*): I will answer the questions raised in the same order as the papers. With regard to Mr. Taylor's difficulty, this merely arises from a misconception of the angle he refers to. I do not dispute his calculations, but the angle which represents the power-factor, or product-factor, is not the angle which he assumes it to be. The paper shows that the mean product of two quantities is less than the product of the means of those quantities as read by alternating-current instruments. The ratio of the two products is thus less than unity, and can be represented by cos ϕ, where ϕ is a real angle. But it does not follow, except in the case of sine currents, that the angle ϕ so calculated is the angle corresponding with the distance between the maxima of the two curves, as Mr. Taylor has assumed. The angle ϕ has to be found from the equation, which equation thus must be correct. What, then, is the use of the equation? The answer is, firstly, that it is always possible to find a real angle ϕ to satisfy the equation; and, secondly, that the angles thus found for different conductors are consistent with geometrical representation. Thus, if two inductive conductors are in series, as in Fig. D, the first taking a

Dr. Sumpner.

voltage V_1, and the second a voltage V_2, and if the voltage across the two in series is V_3, it is always possible to construct a triangle the sides of which represent V_1, V_2, and V_3 in magnitude, and which triangle is also such that the angles between each side and a fourth line representing the current represents the power-factor of the corresponding conductor. Thus in Fig. E, if the line O A represents the current and the lines O Q, Q P, and P O represent respectively the voltages V_1, V_2, and V_3, then it is possible to draw the figure so that cos Q O A is the power-factor of the first conductor, cos P R A is that of the second, and cos P O A that of the third, consisting of the former two in series. The possibility of constructing such a figure can be shown to depend upon the truth of the proposition established in the paper.

In complicated and exceptional cases the figure does not necessarily lie wholly in one plane, and this affords the answer to the second point raised by Mr. Taylor. He points out that the current taken by a synchronous motor alters from a lagging to a leading condition as the exciting current is varied so as to pass through the value for minimum current, and assumes that the power-factor of the motor must be unity for this minimum value. Of course it is obvious that if two lines drawn on a sheet of paper represent the voltage and current taken by the motor the angle between them cannot continuously alter from a positive to a negative value without the lines actually crossing one another, with a zero angle between them, and a power-factor unity. But if the figure is not necessarily confined to one plane, the angle can alter continuously between the two values without passing through zero as an intermediate stage. What Mr. Taylor says of synchronous motors is no doubt essentially true in actual cases, but it is not strictly accurate. A power-factor unity means absolute correspondence between the voltage and current curves, and this, strictly speaking, never happens, even with so-called non-inductive resistances.

In regard to the second paper, Mr. Housman gave some very interesting information about tests with the Kapp and Housman method. He referred to the accurate investigation and separation of small sources of loss. This was not the object I had in view in writing the paper. I aimed at raising a discussion on the most suitable methods of testing machines with simple instruments, and by methods needing few preliminary arrangements. The object was not so much high accuracy, as quickness and simplicity in getting good approximate results.

I agree with Mr. Lea that the conditions under which the testing was carried out are not quite the same as when the dynamo is loaded, but I doubt very much if there is any simple method that takes into account all the losses which will give more correct results. You cannot get any method which will give the losses direct unless you go to the trouble of using the Hopkinson method.

Mr. Housman says he doubts whether the method is applicable to small machines, and in this case I prefer the Kapp and Housman method myself. The method I have described is adapted mainly to testing large machines and alternators.

MANCHESTER LOCAL SECTION

THE BREAKING OF SHAFTS IN DIRECT-COUPLED UNITS, DUE TO OSCILLATIONS SET UP AT CRITICAL SPEEDS.

By JULIUS FRITH, A.M.I.E.E. and ERNEST H. LAMB B.Sc. (Vict.).

(*Paper read December* 17, 1901.)

The design of a shaft to do some particular work is, to many of us, an operation of every-day occurrence, and, judging from the results attained, one which is attended with a very fair amount of success. The maximum stresses induced in the shaft, when considered as an agent for the transmission of power from one machine to another, can, in most cases, be estimated with considerable accuracy; and the calculation of the necessary strength and stiffness to give to the shaft is an operation that presents no particular difficulty, when it appears in the designing room of any engineering works.

Apart from the possibility of hidden flaws in the material of the shaft, there are, however, certain internal causes of weakness, which do not appear to have sufficiently claimed the attention of Engineers.[1] The object of this paper is to point out these causes of weakness; which may occasion the fracture of a perfectly sound shaft, quite independently of the work it is doing, or indeed when it is doing no useful work at all.

Various cases of the failure of engine and dynamo shafts are on record, where the fracture occurred at some particular speed, and could not be attributed to any of the ordinary strains to which they are liable during working, as the shafts were amply strong to endure the maximum strains due to steam pressure and the inertia of the moving parts combined. Hence in such cases we must look for some other possible disturbance as the cause of fracture.

Such occurrences would very naturally point to the fact, that the "free" period of some oscillations of the crank shaft together with the attached masses, synchronised with the period of some external periodic force, acting on the system. We shall show later, that absolute synchronism of these two periods (which is a practical impossibility for any length of time), is not essential to produce the fracture; but that if the two periods approach each other in magnitude, within a certain range, there will be great risk of fracture. We shall also show that

[1] Capt. Sankey, of the well-known firm of Messrs. Willans and Robinson, Ltd., of Rugby, some time ago called attention to this possible cause of fracture; and it was at his suggestion that the present authors were induced to look further into the question.

such fractures can be avoided by suitable adjustment of the stiffness of the shafts, and by some alteration in the moments of inertia of the revolving masses.

At this stage let us consider a few problems in oscillations connected with shafts and masses attached thereto.

Take the case of a shaft, fixed rigidly at one end, with a mass attached to the other end which is free. If we give the attached mass a displacement from its equilibrium position, by twisting the shaft within the elastic limit, and then suddenly release it, it will oscillate with a simple harmonic motion in a period which depends solely on the torsional "stiffness" of the shaft, and the moment of inertia, or rotary inertia, of the attached mass.

In the Appendix to this paper will be found the solution of this problem, the period being given by the formula—

$$T = 2\pi \sqrt{\frac{M}{m_0}}$$

where M is the moment of inertia of the mass about the axis of the shaft, and m_0 is the couple necessary to twist the length of shaft through unit angle.

This problem is analogous to that of a spiral spring, fixed at one end and carrying a mass at the other. If the attached mass be displaced from its equilibrium position by extending or compressing the spring, and then suddenly released, it will oscillate with a simple harmonic motion, with a period depending only on the stiffness of the spring, and the inertia of the attached mass.

Next consider the case of a length of shaft with two attached masses, one at each end. Suppose the shaft supported in bearings, so as to be free to rotate. Let us now give the masses a relative displacement by twisting the shaft between them, within the elastic limit, and then suddenly release it. The masses will oscillate opposite to each other, with a simple harmonic motion, the period depending only on the stiffness of the shaft, and the rotary inertias of the two attached masses.

The solution of this problem is the second which is given in the Appendix; the period being given by

$$T = 2\pi \sqrt{\frac{1}{m_0}\left(\frac{M_1 M_2}{M_1 + M_2}\right)} .$$

where M_1 and M_2 are the moments of inertia of the two masses, m_0 being the couple necessary to twist the shaft through unit angle.

If we now impose upon some part of the system an external periodic couple, whose period is the same as that of the "free" motion of the system which we have just been describing, the amplitude of the oscillations of the masses will gradually increase, until the shaft finally breaks.

The same effect can also be produced in the previous example of a shaft, fixed at one end and carrying a mass at the other.

Furthermore, from the theory of forced oscillations we learn that, in the event of the period of the forced disturbance synchronising with

any period of the free motion of a system, the amplitudes eventually become infinite.

Let us now consider the free oscillations of a system consisting of a shaft carrying three masses, attached at certain intervals of its length. As before, suppose the shaft to rest in bearings so as to be free to rotate. Here it is possible to see at the outset, that the motion is much more complex than in the previous cases which we have been considering. For it is possible to start the oscillations in different ways. For example, we may simply twist the two outer masses in opposite directions and then release them; or we may twist the outer masses in the same direction, while we simultaneously twist the middle mass in the opposite direction, and then release them. These two methods of starting will generally result in obtaining different modes of oscillation of the system. If the system be set oscillating by starting it in any manner, it will be seen that the motion will in general consist of a superposition of the two modes of oscillation which have just been described; and these two modes of oscillation have, in general, different periods.

At first sight it appears as if there were more than two periods in the motion, owing to its complexity, but this is not so. The delusion lies in the fact that there are different states of motion, which depend on the way in which the motion is started. For, in the most general state of motion, the masses all oscillate in a motion compounded of two simple harmonic oscillations, there being no fixed relation between the two amplitudes of the two oscillations. We may, however, by taking proper precautions about starting, get one or other of the periods alone.

The mathematical solution of this problem will also be found in the Appendix, being the third problem there. The solution shows conclusively that there can be only two periods in the free motion of the system.

The two periods are given by expressions of the form—

$$T_1 = \frac{2\pi}{n_1} \text{ and } T_2 = \frac{2\pi}{n_2}$$

where n_1^2 and n_2^2 are the roots of a quadratic equation.

An interesting fact about the two periods of the system is there pointed out.

If M_1 M_2 and M_3 be the rotary inertias of the masses in order along the shaft, it is shown that the two periods of the free motion lie in magnitude outside the two periods of the mono-periodic systems consisting of

(1) The two masses M_1 and M_2 and the length of shaft between them.

(2) The two masses M_2 and M_3 and the length of shaft between them.

A system having a motion compounded of two simple harmonic oscillations, though not analogous to the preceding problem, is the double pendulum, where we can have either of the periods alone, by

taking proper precautions about starting; the most general state of motion being that where the two oscillations are superposed.

If in the above case of the shaft and three attached masses we impose a periodic couple on any part of the system, in the event of the period of the imposed extraneous couple sychronising with either of the periods of the free motion of the system, the amplitude of the oscillation will increase without limit until finally the shaft fractures.

In all the above instances of shafts and attached masses, it will be seen, on referring to the solutions given in the Appendix, that when an extraneous periodic couple acts upon some part of the system, the most general state of motion possible is that where the forced oscillations are superposed on the "free" motion. In all practical cases, however, the free oscillations die out more or less rapidly, at a rate depending on the magnitude of the friction, there being no external forces to maintain this part of the motion.

Before proceeding further with our subject, we would call attention to a few points in connection with the formulæ which we have given.

In the Appendix will be found the method of calculating the couple required to twist a given length of shaft of a given diameter through unit angle. There also is shown the method of applying the calculation to a shaft of varying diameter. It should be noted that the formulæ for the twisting of a shaft do not hold at points where there is a sudden increase or diminution in the diameter; but for approximate calculation the formulæ given are sufficiently accurate.

The next point is of importance, and relates to the choice of a proper system of units for our calculations. If we agree to reckon forces in pounds weight, we must take "g" times one pound as our unit of mass. If "g" is taken as 32 feet per second, we must reckon lengths in feet and areas in square feet.

Hence the modulus of rigidity "C" must be reckoned in pounds weight per square foot.

So far we have confined our attention to problems which admit of fairly exact mathematical analysis; that is to say, we have chosen certain conditions under which the equations of motion of the systems considered admit of simple solutions.

We will now turn our thoughts to what is more directly the subject of our paper, namely, the oscillations of systems, consisting of dynamo armatures, or rotating field magnets and fly-wheels, coupled direct to reciprocating engines.

It is obvious, in the case of an engine coupled direct to an armature and fly-wheel by means of a length of shaft, that this is a system in which it is possible to set up oscillations of the nature which we have just been considering; the period of which depends on the stiffness of the length of shaft between the engine and point of attachment of the fly-wheel, and on the moments of inertia of the fly-wheel and armature, and of the reciprocating parts of the engine about the axis of the shaft.

Now, at first sight, it appears (at least it did appear so to the authors) that any such possible free oscillations in combined sets of the direct-coupled type, would have a period of oscillation very much shorter than the period of the variations in turning moment of the

engine, owing to the great stiffness of the shaft; so that synchronism appeared to be out of the question.

However, on applying calculation to the case of an actual working set, where an engine was coupled direct to two armatures in tandem, we were surprised to get results giving periods of very much the same length as those of the engine beats, thus showing that synchronism and large forced amplitudes were occurrences within reasonable possibility, and consequently that there was danger of fracture occurring either in the shafts, or keys, by which the rotating masses were attached.

It must be borne in mind, however, that calculations of this nature, when applied to such a complex system as a direct-coupled engine and dynamo, can only be regarded as a guide, but yet are often of sufficient value to give warning in case of danger.

That such calculations can only give very approximate results will be easily understood from the following considerations :—

It becomes necessary when considering this question in the design of plant, to calculate the moment of inertia of a mass, such as an armature, when we have only drawings to work from; and since the mass moment of inertia of a body depends upon the fifth power of the linear dimensions multiplied by the density of the material, and the geometrical moment of inertia of an area depends on the fourth power of the linear dimensions, a very small error in measurement will produce a large error in the result.

However, when an armature is made, it is possible to determine its moment of inertia with considerable accuracy experimentally by means of a bi-filar suspension, the formula of which is easily worked out, and is simple to manipulate. See Appendix § VI. Another method which in some cases may be more practicable than the above is to support the armature horizontally by resting the ends of the shaft on horizontal rails. The armature may then be made to oscillate as a compound pendulum by attaching a known weight at a given distance from the axis, thereby bringing the centre of gravity of the whole out of the axis of the shaft. A third method is to support the armature so as to swing about an axis parallel to the axis of the shaft which is horizontal, the formula for the oscillations in this case being given in the Appendix § VII.

The next quantity to be obtained is the moment of inertia of the reciprocating parts of the engine about the axis of the shaft.

This will be found in § V. of the Appendix, where expressions are given for the moments of inertia in different cases, of engines with one crank, two cranks at 180° and at 90° and three cranks at 120°.

The moments of inertia of the reciprocating parts of engines with other arrangements of cranks than those which have been enumerated can be worked out in exactly the same way.

From these results it is seen that for the inertia of the engines on two cranks at right angles, and on three cranks at 120°, we can, for the purposes of calculation, substitute an equivalent fly-wheel whose rotary inertia is that given in the Appendix, and to which may be added the equivalent moment of inertia of the connecting rod due to its transverse displacement. See Appendix § V. Hence, we may consider

an engine coupled to a dynamo as a system consisting of merely a shaft carrying two masses at a certain interval apart. The same substitution can also be made for an engine driving two dynamos on one shaft.

Here we are again met with another difficulty. At what point of the shaft are we to place the fly-wheel equivalent of the engine inertia?

The best solution of this would most probably be to suppose it to have its place midway between the cranks in a two-crank engine, and in the centre of the middle crank for the three-crank engine. Hence, by obtaining the moments of inertia of the different masses on the shaft, and the fly-wheel equivalent for the inertia of the engine, and by making the necessary calculations of the stiffness of the lengths of shaft, we can get a rough idea of the length of the free period or periods of oscillation, for different systems.

Owing to the fact that in an engine of one crank, or two cranks at 180°, the moment of inertia of the reciprocating parts about the axis of the shaft is not constant throughout the revolution of the engine, only a very rough estimate can be made of the periods of oscillation by taking the mean moment of inertia of the reciprocating parts.

Owing to the more recent tendencies in the design of combined plants, where there is only one dynamo coupled to the engine, the inertia of the engine being very small compared with the inertia of the rotating masses and the shaft connecting them being very short, the period of free oscillation will in most cases be very short, and not at all likely to synchronise with the beats of the engine.

However, in plants where an engine is coupled to two dynamos, arranged either in tandem or on each end of the engine shaft, the engine inertia is much greater compared with the inertia of either of the dynamos than in the previous case, and usually this arrangement involves the use of longer shafts, so that we are likely to find longer periods of free oscillation than before. This arrangement is analogous to that of the shaft carrying three masses, the solution of which is given in the Appendix § III., and to which reference has already been made.

In this case also, in the event of either of the periods of free oscillation, synchronising with the period of the variations of moment of the engine, it is very probable that a fracture will occur in some part of the shaft.

There is an important point, to which no reference has been made in this paper so far. What is the effect of the superposed twist in the shaft, due to the fact that there is a resultant flow of momentum through the shaft, due to the turning moment of the engine being transmitted to the dynamo or dynamos as the case may be? The answer to this can be seen by referring to the equations of motion of the different systems given in the Appendix. It does not effect the period at all, but only alters the centre of oscillation.

On the other hand, the friction of the engine pistons and valves and of the bearings, has a tendency slightly to lengthen the periods of the free motion.

In the solutions given in the Appendix, no account has been taken

of the friction of the different systems in practical cases. But as the moment of the friction on the shaft is very small, compared with the couples with which we have been dealing, the resultant effect of friction will be very small. Moreover, as our calculations cannot pretend to be more than a guide, when applied to engines and dynamos, and as the determination of the friction would be very difficult, and as we should require to know the law which connects its magnitude at any instant with the velocity; it is obviously inadvisable to complicate our calculations further by the introduction of this quantity.

The type of solution obtained, when the friction is taken into account in the equations of motion, may be found on referring to any standard work on Differential Equations.

The effect of the oscillations on the pistons of the steam engine will very much resemble the oscillations of the indicator piston which are often plainly seen on the indicator card. Here also the effect of the friction of the piston is negligible, being very small compared with the forces which produce the motion. Some excellent reproductions of the indicator oscillations are shown in the well-known paper by Prof. Osborne Reynolds, F.R.S., and Dr. A. W. Brightmore, on the Steam Engine Indicator, in the *Proc. Inst. C. E.*, 1885.

The next quantity to be determined is the period of the beats of the engine. By this is meant the period of the actual fluctuations in the *steam* turning moment of the engine.

It may be seen, by plotting the curve of turning moment, due to the *steam pressures only*, that we may consider this moment as consisting of two parts:—

(1) The mean turning moment, which is equal to the moment of the steady load on the engine.

(2) An alternating moment, accelerating and retarding the engine; these two effects being superposed.

The latter of these two is the quantity which concerns us most; as we have seen that the effect of the former is merely to change the centre of oscillation.

In a two-crank engine with the cranks set at 180°, there will be only two complete periods in one revolution of the engine. This is the same for both the single and double-acting engine.

With two cranks set at right angles, there will be four complete periods in a revolution, for the double-acting engine.

In a three-crank engine with the cranks set at 120°, there will be three complete periods in a revolution for the single-acting engine, and six for the double-acting engine. This is the state of things in engines, respectively of the Willans & Belliss types. From what has just been said, it appears very improbable that there is any risk of synchronism or of large forced amplitudes in the case of an engine having two cranks at 180°, owing to the low frequency of the engine beats. This is fortunate, as we have seen that the problem is a difficult one for the application of calculation on account of the very varying rotary inertia of the engine.

We have indicated in §§ I., II., and IV. of the Appendix the method by which the forced amplitude may be obtained. In the case of the

shaft carrying three masses, the quantity $(F_1 - F_2)$ gives the maximum twist between the masses (M_1 and M_2) and the quantity $(F_3 - F_2)$, which differs from $(F_1 - F_2)$ only in the numerator, gives the maximum twist between M_2 and M_3 due to the forcing of the oscillations.

In conclusion, we would point out that it is impossible in a paper of this kind to enumerate all the different arrangements of armatures and fly-wheels on engine shafts, which are adopted in modern practice; but, on the other hand, we have indicated methods, and given formulæ, which we trust will be applicable in some measure to most of the more usual arrangements of combined plants.

Here, again, we must remind the reader that our object has not been to show how to calculate the periods of free motion of the different systems with minute accuracy, as this is an impossibility. Calculations of this nature can only be regarded as a guide, and, in consequence, we recommend that in the design of plants these calculations should be applied to the shafts; and, in the event of the results giving periods of at all the same magnitude as the period of the engine beats, that the shafts should be properly stiffened until all chance of synchronism is out of the question, and the forced amplitudes, which it must be remembered, exist under all conditions, become sufficiently small to produce no injurious effects. The method of calculating the magnitude of the variations in stress, and of the total stresses induced in the shaft due to torsion, is shown in Nos. (8) and (9) of § IV. in the Appendix. As is well known, we may here draw attention to the fact that, as the forced oscillations produce alternations in the stresses in the material of the shaft, the ultimate strength of the material is thereby considerably reduced, and consequently the factor of safety employed must be increased. It is most probable that in nine cases out of ten the possibility of synchronism will only appear in high-speed sets, and the majority of these in plants where an engine is coupled to two dynamos, though in some instances of an engine driving one dynamo, where the fly-wheel is separated from the armature by a bearing, it is likely that the oscillation will have a comparatively long period.

For another type of shaft oscillation we would refer to the paper by Prof. Dunkerley, in the *Phil. Trans. Roy. Soc.*, Section A., 1894, on the centrifugal "Whirling of Shafts," where the calculation of the transverse oscillations is involved. The numerous experiments there described were made at Owens College, Manchester, and are of interest where the unsupported lengths of shaft are great. In most modern arrangements of engines and dynamos, however, the shafts are laterally very stiff and the lengths short, and it is very doubtful if such oscillations ever occurred in these instances.

There is one other point which may occur to the reader, which it may be well to mention here. In the case of an engine driving two dynamos, which part of the shaft is most likely to fracture? That is to say, which part is to be strengthened most, with the object of avoiding all chance of synchronism?

The quantities $(F_1 - F_2)$ and $(F_3 - F_2)$ in § IV. of the Appendix would serve as a guide in this; but it is very doubtful whether the results of calculation are sufficiently accurate for this purpose.

APPENDIX.

SOLUTIONS OF PROBLEMS IN TORSIONAL OSCILLATIONS OF VARIOUS SYSTEMS OF SHAFTS AND ATTACHED MASSES.

First to obtain the necessary relation between the angle of twist of a length of shaft, and the couple producing it.

Let l = length of shaft.
" I = moment of inertia of *section* of shaft.
" θ = angle of twist of the whole length "l".
" $2r$ = diameter of shaft.
" f = maximum shearing stress.
" C = modulus of rigidity for material of shaft.

Now if m = twisting couple, we have—

$$\frac{m}{\mathrm{I}}=\frac{f}{r} \text{ and } \frac{f}{\mathrm{C}}=\frac{r\theta}{l}$$

$$\therefore \frac{m}{\mathrm{I}}=\frac{\mathrm{C}\theta}{l}.$$

$$i.e., \; m=\frac{\mathrm{C\,I}}{l}.\ \theta.$$

Hence if θ = the unit of circular measure, *i.e.*, one radian, we see that the quantity $\frac{\mathrm{C\,I}}{l}$ is the moment of the couple necessary to twist the length of shaft through unit angle.

This result may easily be extended to a length of shaft where the diameter is not constant, *i.e.*, a shaft made up of lengths of different diameters.

For if the shaft consists of lengths l_1, l_2, . . . etc., of diameters $2r_1$, $2r_2$, . . . etc.

We have—

$$\theta_1=\frac{l_1}{\mathrm{CI}_1}\ m$$

$$\theta_2=\frac{l_2}{\mathrm{CI}_2}\ m. \ . \ . \ \text{etc.}$$

$\therefore$ total angle of twist $=\theta_1+\theta_2+\theta_3$ . . . etc.

$$=\frac{m}{\mathrm{C}}\left[\frac{l_1}{\mathrm{I}_1}+\frac{l_2}{\mathrm{I}_2}+\frac{l_3}{\mathrm{I}_3}+\text{etc.}\ .\ .\ .\right]=\frac{m}{\mathrm{C}}\,\Sigma\left(\frac{l}{\mathrm{I}}\right).$$

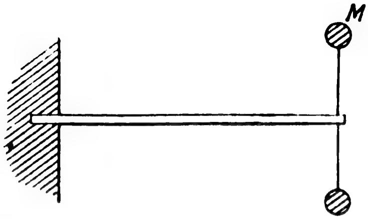
$$\therefore m=\frac{\mathrm{C}}{\Sigma\left(\frac{l}{\mathrm{I}}\right)}\theta.$$

Hence the couple necessary to twist any length of shaft through unit angle is given by—

$$m_o=\frac{\mathrm{C}}{\Sigma\left(\frac{l}{\mathrm{I}}\right)}.$$

Hence also $m=\theta.\ m_o$.

(I.) Solution of the equations of motion for a shaft supported in bearings, fixed at one end and carrying a fly-wheel at the other end which is free.



Let M = moment of inertia of fly-wheel.
" m_o = couple required to twist the shaft through unit angle.
If m = twisting couple at any instant, we have :—

$$M\frac{d^2\theta}{dt^2} + m = 0$$

or—

$$M\frac{d^2\theta}{dt^2} + m_o \cdot \theta = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The solution of this is easily shown to be—

$$\theta = a \cos\left(\sqrt{\frac{m_o}{M}} \cdot t + \epsilon\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence the motion has one period which is given by—

$$T = 2\pi\sqrt{\frac{M}{m_o}}$$

where m_o may be calculated as above.

If an extraneous periodic couple acts upon the mass M, whose period is $\frac{2\pi}{\lambda}$ and whose maximum value is P; the equation of motion takes the following form—

$$M\frac{d^2\theta}{dt^2} + m_o\theta = P\cos\lambda t,$$

i.e.—

$$\frac{d^2\theta}{dt^2} + \frac{m_o}{M}\theta = \frac{P}{M}\cos\lambda t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The particular integral of this, which gives the forced motion, is obtained by making the substitution—

$$\theta = F\cos\lambda t + G\sin\lambda t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

On substituting in (3) and equating coefficients of $\cos\lambda t$ and $\sin\lambda t$ respectively we obtain—

$$G = 0,$$

and—

$$F = \frac{\frac{P}{M}}{\left(\frac{m_o}{M} - \lambda^2\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Hence the particular solution is—

$$\theta = \frac{\frac{P}{M}}{\left(\frac{m_o}{M} - \lambda^2\right)} \cos \lambda t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

the complete solution of (3) being the sum of the two solutions (2) and (6).

The solution (6), however, fails when $\lambda^2 = \frac{m_o}{M}$; in this case the proper substitution is—

$$\theta = Q\, t \sin \lambda t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

On substituting in (3) we get—

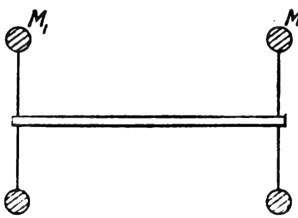
$$Q = \frac{P}{2 \lambda M}$$

Hence—

$$\theta = \frac{P}{2 \lambda M}\, t \sin \lambda t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

This is the solution for the case of synchronism, and shows that the amplitude increases indefinitely with the time.

(II.) Solution of the equations of motion for a shaft supported in bearings, and carrying masses at each end; the whole being free to rotate.



As before, let M_1 and M_2 be the moments of inertia of the masses. Let m_o be the couple necessary to twist the shaft through unit angle.

Let m be the twisting couple at any instant. Let θ_1 and θ_2 be the angular displacements relative to some fixed direction, there being no aggregate rotation of the system. Hence the equations of the "free" motion are—

$$\left.\begin{aligned} M_1 \frac{d^2 \theta_1}{dt^2} - m &= 0 \\ M_2 \frac{d^2 \theta_2}{dt^2} + m &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

i.e.

$$\left.\begin{aligned} \frac{d^2 \theta_1}{dt^2} - \frac{m_o}{M_1}(\theta_2 - \theta_1) &= 0 \\ \frac{d^2 \theta_2}{dt^2} + \frac{m_o}{M_2}(\theta_2 - \theta_1) &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence subtracting these equations :—

$$\frac{d_2(\theta_2 - \theta_1)}{dt^2} + (\theta_2 - \theta_1)\, m_o \left(\frac{1}{M_1} + \frac{1}{M_2}\right) = 0 \quad . \quad . \quad . \quad . \quad (3)$$

The solution of which is—

$$(\theta_2 - \theta_1) = a \cos \left\{ \sqrt{m_o\left(\frac{1}{M_1} + \frac{1}{M_2}\right)} \cdot t + \epsilon \right\} \quad . \quad . \quad (4)$$

Hence the motion has but one period, which is given by—

$$T = 2\pi \sqrt{\frac{1}{m_o} \cdot \frac{M_1 M_2}{M_1 + M_2}}.$$

If an extraneous periodic couple acts upon the mass M_2, whose period is $\frac{2\pi}{\lambda}$, and whose maximum value is P, the equations of motion take the following form :—

$$\left.\begin{aligned} \frac{d^2\theta_1}{dt^2} - \frac{m_o}{M_1}(\theta_2 - \theta_1) &= 0 \\ \frac{d^2\theta_2}{dt^2} + \frac{m_o}{M_2}(\theta_2 - \theta_1) &= \frac{P}{M_2}\cos \lambda t \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Hence, as before, by subtracting the first from the second of these two equations we get—

$$\frac{d^2(\theta_2 - \theta_1)}{dt^2} + (\theta_2 - \theta_1) \cdot m_o\left(\frac{1}{M_1} + \frac{1}{M_2}\right) = \frac{P}{M_2}\cos \lambda t \quad . \quad . \quad (6)$$

The particular solution of this, which gives the forced motion, is obtained as in § I., giving—

$$\theta_2 - \theta_1 = \frac{\frac{P}{M_2}}{\left\{ m_o\left(\frac{1}{M_1} + \frac{1}{M_2}\right) - \lambda^2 \right\}} \cos \lambda t \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

the complete solution of (6) being the sum of the solutions (4) and (7).

As before, for the case of synchronism we get—

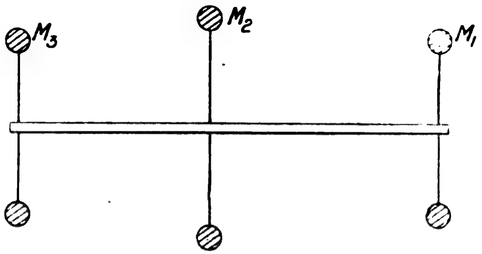
$$\theta_2 - \theta_1 = \frac{P}{2\lambda M_2} t \sin \lambda t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

From (7) we see that, if ψ be the angle of twist necessary to just overstrain the shaft, then for all periods of the extraneous couple *between* the two values (supposing P to be constant), for which—

$$\pm \psi = \frac{\frac{P}{M_2}}{\left\{ m_o\left(\frac{1}{M_1} + \frac{1}{M_2}\right) - \lambda^2 \right\}}$$

the amplitudes of the forced oscillation will be sufficient to overstrain the shaft.

(III.) Solution of the equations of motion for a shaft supported in bearings, and carrying three masses at fixed intervals of its length; the whole being free to rotate.



Let the moments of inertia of the masses be M_1 M_2 and M_3.
Let m_{o1} be the couple required to twist the length between M_1 and M_2 through unit angle.
Let m_{o2} be the couple required to twist the length between M_2 and M_3 through unit angle.
Now the equations of the free motion of the system are—

$$\left.\begin{aligned} M_1 \frac{d^2\theta_1}{dt^2} - m_1 &= 0 \\ M_2 \frac{d^2\theta_2}{dt^2} - m_2 + m_1 &= 0 \\ M_3 \frac{d^2\theta_3}{dt^2} + m_2 &= 0 \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (1)$$

Where m_1 and m_2 are the simultaneous twisting couples in the two intervals of shaft at any instant; and θ_1 θ_2 and θ_3 are the angles of displacement of the masses measured relatively to some fixed direction; there being no aggregate rotation of the system.

Now putting $\left.\begin{aligned} m_1 &= (\theta_2 - \theta_1)\, m_{o1} \\ m_2 &= (\theta_3 - \theta_2)\, m_{o2} \end{aligned}\right\}$

and dividing out by M_1 M_2 and M_3, the equations (1) become—

$$\left.\begin{aligned} &\frac{d^2\theta_1}{dt^2} + \frac{m_{o1}}{M_1}(\theta_1 - \theta_2) = 0 \\ &\frac{d^2\theta_2}{dt^2} + \frac{m_{o1}}{M_2}(\theta_2 - \theta_1) + \frac{m_{o2}}{M_2}(\theta_2 - \theta_3) = 0 \\ &\frac{d^2\theta_3}{dt^2} + \frac{m_{o2}}{M_3}(\theta_3 - \theta_2) = 0 \end{aligned}\right\} \quad \ldots\ldots \quad (2)$$

These are Simultaneous Linear Equations of the Second Order, and may be solved as follows:—

$$\text{Assume } \begin{aligned} \theta_1 &= a \cos(nt + \epsilon) \\ \theta_2 &= \beta \cos(nt + \epsilon) \\ \theta_3 &= \gamma \cos(nt + \epsilon) \end{aligned}$$

Substitute these in the equations (2), and divide out by cos $(nt+\epsilon)$. On re-arranging the terms we get—

$$\left.\begin{aligned} \alpha \cdot \left(n^2 - \frac{m_{o1}}{M_1}\right) + \beta \cdot \frac{m_{o1}}{M_1} + \gamma \cdot o &= o \\ \alpha \cdot \frac{m_{o1}}{M_2} + \beta \cdot \left(n^2 - \frac{m_{o1}}{M_2} - \frac{m_{o2}}{M_2}\right) + \gamma \cdot \frac{m_{o2}}{M_2} &= o \\ \alpha \cdot o + \beta \cdot \frac{m_{o2}}{M_3} + \gamma \cdot \left(n^2 - \frac{m_{o2}}{M_3}\right) &= o \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (3)$$

These three equations determine the *ratios* $\frac{\alpha}{\beta}$, $\frac{\beta}{\gamma}$ and n^2.

To obtain the values of n^2, eliminate α, β, and γ; this gives the equation—

$$\begin{vmatrix} n^2 - \frac{m_{o1}}{M_1}, & \frac{m_{o1}}{M_1}, & o, \\ \frac{m_{o1}}{M_2}, & n^2 - \frac{1}{M_2}(m_{o1}+m_{o2}), & \frac{m_{o2}}{M_2}, \\ o, & \frac{m_{o2}}{M_3}, & n^2 - \frac{m_{o2}}{M_3} \end{vmatrix} = o \quad . \quad . \quad . \quad (4)$$

It will be noticed here that, by adding the columns together, n^2 is a factor. Also by replacing the middle column by the sum of the last two columns, the determinant becomes—

$$n^2 \begin{vmatrix} 1, & \frac{m_{o1}}{M_1}, & o \\ 1, & \left(n^2 - \frac{m_{o1}}{M_2}\right), & \frac{m_{o2}}{M_2} \\ 1, & n^2, & n^2 - \frac{m_{o2}}{M_3} \end{vmatrix} = o \quad . \quad . \quad . \quad . \quad (5)$$

On multiplying out this determinant, we get the following cubic equation in n^2, of which one root is zero :—

$$n^2 \left\{ n^4 - n^2\left(\frac{m_{o1}}{M_1} + \frac{m_{o2}}{M_2} + \frac{m_{o1}}{M_2} + \frac{m_{o2}}{M_3}\right) + m_{o1} m_{o2}\left(\frac{1}{M_1 M_2} + \frac{1}{M_2 M_3} + \frac{1}{M_3 M_1}\right)\right\} = o.$$

That is $n^2 = o$ or—

$$n^4 - n^2\left\{ m_{o1}\left(\frac{1}{M_1}+\frac{1}{M_2}\right) + m_{o2}\left(\frac{1}{M_2}+\frac{1}{M_3}\right)\right\} + m_{o1} m_{o2}\left\{\frac{1}{M_1 M_2} + \frac{1}{M_2 M_3} + \frac{1}{M_3 M_1}\right\} = o \quad . \quad . \quad (6)$$

Hence if n_1^2 and n_2^2 are the roots of this equation, we see that the motion has two periods only, which are given by—

$$T_1 = \frac{2\pi}{n_1} \text{ and } T_2 = \frac{2\pi}{n_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Put

$$A = \left\{ m_{01}\left(\frac{1}{M_1} + \frac{1}{M_2}\right) + m_{02}\left(\frac{1}{M_2} + \frac{1}{M_3}\right) \right\}$$

and

$$B = m_{01}\, m_{02} \left\{ \frac{1}{M_1 M_2} + \frac{1}{M_2 M_3} + \frac{1}{M_3 M_1} \right\}$$

Then n_1^2 and n_2^2 are given by—

$$\left.\begin{matrix} n_1^2 \\ n_2^2 \end{matrix}\right\} = \frac{1}{2} A \pm \frac{1}{2}\sqrt{A^2 - 4B} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Consider now the two quantities—

$$m_{01}\left(\frac{1}{M_1} + \frac{1}{M_2}\right) = p^2 (\text{say})$$

$$m_{02}\left(\frac{1}{M_2} + \frac{1}{M_3}\right) = q^2 (\text{say})$$

Since n_1^2 and n_2^2 are the roots of (6)

$$n_1^2 + n_2^2 = p^2 + q^2$$

also

$$p^2 q^2 = m_{01}\, m_{02} \left\{ \frac{1}{M_1 M_2} + \frac{1}{M_2 M_3} + \frac{1}{M_3 M_1} + \frac{1}{M_2^2} \right\}$$

$$\therefore \; n_1^2 n_2^2 < p^2 q^2.$$

Hence p^2 and q^2 lie, in magnitude, between the values of n_1^2 and n_2^2.

Hence one period of the motion is greater than the greatest of the two quantities $\frac{2\pi}{p}$, $\frac{2\pi}{q}$, and the other period is less than the least of these quantities.

Hence the two periods of the system lie, in magnitude, outside the periods of the two mono-periodic systems :—

(1) composed of the masses M_1 and M_2 and the length of shaft between them, whose period is $\frac{2\pi}{p}$, and

(2) composed of the masses M_2 and M_3 and the length of shaft between them, whose period is $\frac{2\pi}{q}$.

The complete solution of the equations of the "free" motion is—

$$\left.\begin{aligned} \theta_1 &= \alpha_1 \cos(n_1 t + \epsilon_1) + \alpha_2 \cos(n_2 t + \epsilon_2) + \alpha_3 \cos \epsilon_3 \\ \theta_2 &= \beta_1 \cos(n_1 t + \epsilon_1) + \beta_2 \cos(n_2 t + \epsilon_2) + \beta_3 \cos \epsilon_3 \\ \theta_3 &= \gamma_1 \cos(n_1 t + \epsilon_1) + \gamma_2 \cos(n_2 t + \epsilon_2) + \gamma_3 \cos \epsilon_3 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

This solution contains the 12 constant quantities :—

$$\alpha_1,\ \alpha_2,\ \alpha_3,\ \beta_1,\ \beta_2,\ \beta_3,\ \gamma_1,\ \gamma_2,\ \gamma_3,\ \epsilon_1,\ \epsilon_2,\ \epsilon_3.$$

But the ratios $\frac{\alpha_1}{\beta_1}$, $\frac{\alpha_2}{\beta_2}$, $\frac{\alpha_3}{\beta_3}$, $\frac{\beta_1}{\gamma_1}$, $\frac{\beta_2}{\gamma_2}$, $\frac{\beta_3}{\gamma_3}$, are given by equations (3), on substituting the different values of n^2.

Hence finally the solution contains only 6 arbitrary constants.

(IV.) The equations of motion for the above system, when an extraneous periodic couple acts upon the mass M_1, whose period is $\frac{2\pi}{\lambda}$ and whose maximum value is P; take from the following form :—

$$\left.\begin{aligned} &\frac{d^2\theta_1}{dt^2} + \frac{m_{o1}}{M_1}(\theta_1 - \theta_2) = \frac{P}{M_1}\cos\lambda t. \\ &\frac{d^2\theta_2}{dt^2} + \frac{m_{o1}}{M_2}(\theta_2 - \theta_1) + \frac{m_{o2}}{M_2}(\theta_2 - \theta_3) = 0 \\ &\frac{d^2\theta_3}{dt^2} + \frac{m_{o2}}{M_3}(\theta_3 - \theta_2) = 0 \end{aligned}\right\} \quad . \; . \; . \quad (1)$$

The particular integrals of these may be obtained by making the substitution—

$$\left.\begin{aligned} \theta_1 &= F_1\cos\lambda t + G_1\sin\lambda t \\ \theta_2 &= F_2\cos\lambda t + G_2\sin\lambda t \\ \theta_2 &= F_3\cos\lambda t + G_3\sin\lambda t \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

On equating coefficients of $\cos\lambda t$ and $\sin\lambda t$, we get 6 equations, from which we see that—

$$G_1 = G_2 = G_3 = 0$$

and F_1, F_2 and F_3 are given by the 3 equations—

$$\left.\begin{aligned} &-F_1\lambda^2 + \frac{m_{o1}}{M_1}(F_1 - F_2) = \frac{P}{M_1} \\ &-F_2\lambda^2 + \frac{m_{o1}}{M_2}(F_2 - F_1) + \frac{m_{o2}}{M_2}(F_2 - F_3) = 0 \\ &-F_3\lambda^2 + \frac{m_{o2}}{M_3}(F_3 - F_2) = 0 \end{aligned}\right\} \quad . \; . \; . \quad (3)$$

from which we obtain—

$$F_1 - F_2 = \frac{\frac{P}{M_1}\left\{\lambda^2 - m_{o2}\left(\frac{1}{M_2} + \frac{1}{M_3}\right)\right\}}{\frac{m_{o1}m_{o2}}{M_2^2} - \left\{\lambda^2 - m_{o1}\left(\frac{1}{M_1} + \frac{1}{M_2}\right)\right\}\left\{\lambda^2 - m_{o2}\left(\frac{1}{M_2} + \frac{1}{M_3}\right)\right\}} \quad . \; . \; . \; . \; . \; . \; . \quad (4)$$

$$F_3 - F_2 = \frac{\frac{P}{M_1}\,\frac{m_{o1}}{M_2}}{\frac{m_{o1}m_{o2}}{M_2^2} - \left\{\lambda^2 - m_{o1}\left(\frac{1}{M_1} + \frac{1}{M_2}\right)\right\}\left\{\lambda^2 - m_{o2}\left(\frac{1}{M_2} + \frac{1}{M_3}\right)\right\}} \quad . \; . \; . \; . \; . \; . \; . \quad (5)$$

These give the maximum twist in each length of shaft due to the forced oscillations.

The complete solution of the equations (1), consists of the solution (2) together with the solution for the "free" motion given in § III.

The "particular" solution given in (2), however, breaks down in the event of synchronism. In this case it can be shown that the amplitude increases indefinitely with the time.

By an exactly similar process, if an extraneous periodic couple acts upon the mass M_2, we get the following values for $(F_1 - F_2)$ and $(F_3 - F_2)$—

$$F_1 - F_2 = \frac{\frac{P}{M_2}\left(\frac{m_{o2}}{M_3} - \lambda^2\right)}{\frac{m_{o1}\, m_{o2}}{M_2^2} - \left\{\lambda^2 - m_{o1}\left(\frac{1}{M_1} + \frac{1}{M_2}\right)\right\}\left\{\lambda^2 - m_{o2}\left(\frac{1}{M_2} + \frac{1}{M_3}\right)\right\}} \quad \ldots\ldots \quad (6)$$

$$F_3 - F_2 = \frac{\frac{P}{M_2}\left(\frac{m_{o1}}{M_1} - \lambda^2\right)}{\frac{m_{o1}\, m_{o2}}{M_2^2} - \left\{\lambda^2 - m_{o1}\left(\frac{1}{M_1} + \frac{1}{M_2}\right)\right\}\left\{\lambda^2 - m_{o2}\left(\frac{1}{M_2} + \frac{1}{M_3}\right)\right\}} \quad \ldots\ldots \quad (7)$$

As in the end of § II., if we know the angles of twist necessary to overstrain the lengths of shafting, then for any given value of P we can find the range of values of λ, which will give forced amplitudes sufficient to overstrain the shaft. Another point of interest in the above results is that the ratio $(F_1 - F_2) : (F_3 - F_2)$ in both cases is independent of the rotary inertia of the mass upon which the extraneous periodic couple acts, and is also independent of the magnitude of this couple.

From the results (4), (5), (6) and (7) given above, and from (7) of § II., we see that the total twist in a length of shaft, between any two consecutive masses, due to torsional oscillation, is of the form—

$$\theta_a - \theta_b = P G \cos \lambda t \quad \ldots\ldots\ldots \quad (8)$$

where G is a constant depending on the speed of the engine, and on the general configuration of the system of shaft and attached masses; and P is the maximum deviation of the part of the steam turning-moment of the engine which is transmitted by the shaft, from its mean value.

Now, if H = mean turning-moment transmitted by the shaft, and m_o = couple necessary to twist the length of shaft through unit angle, then the twist due to the mean turning-moment is $\frac{H}{m_o}$, and the maximum twist due to oscillation is PG. Hence the total twist in the shaft due to both these causes, varies continually between—

$$\frac{H}{m_o} \pm P G \quad \ldots\ldots\ldots \quad (9)$$

Hence the maximum twisting couple induced in the shaft is—

$$H + P G m_o,$$

from which, the maximum stress in the shaft due to torsion can be calculated in the ordinary way.

(V.) Determination of the moment of inertia of the reciprocating parts of an engine, about the axis of the shaft.

Let r = length of crank.

„ θ = angle between the crank and line of centres at any instant.

„ W = weight of reciprocating parts in pounds.

„ M = required moment of inertia.

Then neglecting the obliquity of the connecting rod we have—

$$M = \frac{W}{g} r^2 \sin^2 \theta = \frac{1}{2} \frac{W}{g} r^2 (1 - \cos 2\theta).$$

Hence for a single-crank engine, the moment of inertia varies between 0, and $\frac{W}{g} r^2$, in a revolution, the mean value being $\frac{W}{2g} r^2$.

For two cranks at 180°, carrying reciprocating weights W_1 and W_2, the moment of inertia of the reciprocating parts is—

$$M = \frac{r^2}{2g} (1 - \cos 2\theta)(W_1 + W_2)$$

which varies between 0 and $\frac{r^2}{g}(W_1 + W_2)$ in a revolution.

The mean value being—

$$\frac{r^2}{2g}(W_1 + W_2)$$

For two cranks at right angles—

$$M = \frac{r^2}{2g} \left\{ W_1 + W_2) - \cos 2\theta \,.\, (W_1 - W_2) \right\}$$

Hence if $W_1 = W_2$

$$M = \frac{W_1 r^2}{g}$$

which is constant throughout the revolution of the engine.

In a similar way it can be shown that, for an engine with three cranks at 120°, if the weights on all three cranks are equal, the moment of inertia is constant throughout a revolution of the engine, and is given by—

$$M = \frac{3}{2} \frac{W}{g} r^2$$

where W is the weight on each crank.

To find the moment of inertia equivalent about the axis of the shaft, for the transverse displacement of the connecting rod.

Let I′ = moment of inertia of connecting rod about the cross-head pin.

Let W′ be the equivalent mass in pounds on the crank pin, due to the *transverse* displacement of the rod only.

If l = length of connecting rod, we have—

$$I' = \frac{W'}{g} \cdot l^2.$$

$$\therefore \frac{W'}{g} = \frac{I'}{l^2}.$$

Hence if r is length of crank, and θ the angle between the crank and line of centres, the equivalent moment of inertia "M" for one crank is—

$$M = \frac{W'}{g} \cdot r^2 \cos^2\theta = \frac{I'}{l^2} \cdot \frac{r^2}{2}(1 + \cos 2\theta).$$

Hence as before, with two cranks at 90° or three cranks at 120°; with similar connecting rods on each crank, this quantity becomes constant throughout a revolution.

(VI.) To determine the moment of inertia of an armature by means of a bifilar suspension.

Let the armature be suspended with its axis vertical, from two diametrically opposite points, equidistant from the axis, by two parallel wires or cables.

Let l = length of each cable, and $2a$ = distance between them.

„ W = weight of armature in pounds.

Then if θ is the angle of rotation of the armature from its position of equilibrium; and if ϕ is the corresponding angle which the cables make with the vertical.

If T' = tension in each rope,

$$T' = \frac{W}{2},$$

and when θ is small

$$2a\, T' \sin\phi = \frac{2a^2\theta}{l} T' = \frac{a^2\theta}{l} \cdot W.$$

Hence for a small oscillation—

$$\frac{W}{g} k^2 \frac{d^2\theta}{dt^2} + \frac{a^2\theta}{l} \cdot W = 0$$

where k is radius of gyration.

$$\therefore \frac{d^2\theta}{dt^2} + \frac{a^2}{k^2} \cdot \frac{g}{l} \cdot \theta = 0$$

$\therefore$ period is—

$$T = 2\pi\sqrt{\frac{l}{g} \cdot \frac{k^2}{a^2}}.$$

from which

$$k^2 = \frac{T^2}{4\pi^2} \cdot \frac{g a^2}{l}.$$

(VII.) Another method of determining the moment of inertia of an armature is to support it with its axis horizontal in such a manner that

it can swing about an axis, parallel to its axis of rotation, the period in this case being given by—

$$T = 2\pi\sqrt{\frac{h^2 + k^2}{h g}},$$

from which—

$$k^2 = \frac{T^2}{4\pi^2} \cdot h g - h^2,$$

where h = distance of the fixed axis from the axis of the shaft.

(VIII.) Note on the dimensions of the quantities involved in the above solutions.

If T denotes time in seconds, and L denotes length in feet, and if W denotes weight in pounds, "g" is an acceleration and is therefore of the dimensions—

$$\frac{(L)}{(T)^2}$$

"M" is a moment of inertia, and is therefore of the dimensions—

$$\frac{(W)}{g} \times (L)^2 = (W) \times (T)^2 \times (L).$$

"C" which is force in pounds weight per sq. ft. is of the dimensions—

$$\frac{(W)}{(L)^2}$$

Hence the expression for a period which is of the same dimensions as the quantity—

$$\sqrt{\frac{1}{C} \cdot \frac{l}{r^4} \cdot M.}$$

is of the dimensions—

$$\sqrt{\frac{(L)^2}{(W)} \times \frac{(L)}{(L)^4} \times (W) \times (T)^2 \times (L)}$$
$$= \sqrt{(T)^2} = (T)$$

that is, it is a "time."

These are points to be carefully observed in the manipulation of the formulæ.

(IX.) Numerical example giving the periods of free oscillation for a three-crank single-acting engine, driving two dynamos in tandem on the same shaft. This case has been chosen as it involves the use of the formulæ of § III., and will also serve to illustrate the method of applying calculation to the simpler formulæ of § II.

To avoid confusion, the units employed are those indicated above, and are as follows :—

The unit of length is one foot.
" " " mass is "g" times one pound.
" " " time is one second.

Using the symbols of § III.,

let M_1 = moment of inertia of engine about the shaft.

M_2 = " " " first armature and flywheel.

M_3 = " " " second armature.

M_1 is calculated as in § V., from which we get—

$M_1 = 30$ in pounds × (feet)$^2 \div g$,

also $M_2 = 680$ " " "

$M_3 = 200$ " " "

The quantities m_{01} and m_{02}, which are the measures of the stiffnesses of the lengths of shaft between M_1 and M_2, and M_2 and M_3 respectively, are calculated as in the beginning of this Appendix, the value of C being taken as $= 1{\cdot}75 \times 10^9$ pounds per square foot. From which we get—

$$m_{01} = 4{\cdot}6 \times 10^6 \text{ feet-pounds.}$$
$$m_{02} = {\cdot}92 \times 10^6 \quad "$$

Hence from § III.—

$$A = \left\{ m_{01} \left(\frac{1}{M_1} + \frac{1}{M_2}\right) + m_{02} \left(\frac{1}{M_2} + \frac{1}{M_3}\right) \right\}$$

$$= 10^6 \left\{ 4{\cdot}6 \left(\frac{1}{30} + \frac{1}{680}\right) + {\cdot}92 \left(\frac{1}{680} + \frac{1}{200}\right) \right\}$$

$$= 10^6 \left\{ {\cdot}160 + {\cdot}006 \right\} = 10^6 \times {\cdot}166$$

$$B = m_{01}\, m_{02} \left\{ \frac{1}{M_1 M_2} + \frac{1}{M_2 M_3} + \frac{1}{M_3 M_1} \right\}$$

$$= 10^{12} \times 4{\cdot}6 \times {\cdot}92 \left\{ \frac{1}{20{,}400} + \frac{1}{136{,}000} + \frac{1}{6000} \right\}$$

$$= 10^{12} \times 4{\cdot}23 \left\{ {\cdot}000049 + {\cdot}00000735 + {\cdot}0001685 \right\}$$

$$= 10^6 \times 4{\cdot}23 \times 222{\cdot}8 = 10^6 \times 944$$

$$\therefore \left.\begin{matrix} n_1^2 \\ n_2^2 \end{matrix}\right\} = \frac{1}{2} \left\{ A \pm \sqrt{A^2 - 4B} \right\}$$

$$= \frac{10^6}{2} \left\{ {\cdot}166 \pm \sqrt{{\cdot}0275 - 00387} \right\}$$

$$= 10^6 \left\{ {\cdot}083 \pm {\cdot}076 \right\}$$

$$\therefore \left.\begin{aligned} n_1^2 &= 10^6 \times {\cdot}159 \\ n_2^2 &= 10^6 \times {\cdot}007 \end{aligned}\right\}$$

$$\therefore \left.\begin{aligned} n_1 &= 10^3 \times {\cdot}4 = 400 \text{ nearly} \\ n_2 &= 10^3 \times {\cdot}0838 = 83{\cdot}8 \text{ nearly} \end{aligned}\right\}$$

$$\therefore \left.\begin{aligned} T_1 &= \frac{2\pi}{400} = \frac{6{\cdot}28}{400} = {\cdot}015 \text{ of a second} \\ T_2 &= \frac{2\pi}{83{\cdot}8} = \frac{6{\cdot}28}{83{\cdot}8} = {\cdot}075 \text{ of a second} \end{aligned}\right\}$$

Now, the speed of the engine is 320 revolutions per minute, and, being of the three-crank single-acting type, the variations in turning moment all go through three complete periods in a revolution. Hence the period of the variations in turning moment is :—

$$\frac{60}{3\,\bar{N}} = \frac{60}{320 \times 3} = \cdot 062 \text{ of a second, where}$$

$$N = \text{revolutions per minute.}$$

Hence it is obvious that the period of the fluctuations in turning moment is a little shorter than T_2, but is considerably greater than T_1. Hence, if the engine were to run at about 267 revolutions per minute for any length of time, there would be considerable risk of damage occurring to the shaft or keys by which the rotating masses are attached ; as this is the speed at which the period of the fluctuations in turning moment is about equal to T_2.

NEWCASTLE LOCAL SECTION.

ELECTRIC CAR EQUIPMENTS AND THEIR MAINTENANCE.

Abstract of a Paper read at Meeting of December 16, 1901.

By A. W. WIGRAM, Associate.

CAR EQUIPMENT.

Single Trucks.—The weak point in the design is the poor support given to the car body at the ends, but this is easily overcome by fitting cantilever extension pieces. These will greatly steady the car when running, and will effectually prevent the body from sagging. The disadvantage of the type is length of the overhang of body and platform compared to the wheel base, which causes the car to take points badly, though the fault is mainly in the track, the point tongue being usually too blunt and coming off at too sharp an angle.

Maximum Traction Trucks will give trouble by uneven wearing of the body supports, unless means are taken to compel the trucks always to swivel round a definite fixed point. It is very difficult to adjust the brakes properly, and on hilly lines or in urban work with many stops the driving wheels are soon worn away by slipping.

Brakes.—The ordinary hand brake leaves little to be desired for light cars, though the application of the power by a direct pull bends the platform. Some other method of simple gearing should be adopted whereby the strain is as far as possible confined to the truck. Many cars are sent out with flat S release springs, incapable of adjustment. This is a great mistake. The whole brake system is a quadrilateral suspended by four links at the corners, and free to move, to a limited extent, along the diagonals. Consequently, as one spring is sure to be stronger or one link stiffer than the rest, the whole system is pulled out of square, so that two brake blocks at opposite corners are continually rubbing on the wheels. The best form is a helical spring about 8 in. long, having an extension of 1 in. for 60 lb. to 80 lb. and ⅝ in. adjusting bolts. If the brake system is kept properly free a very slight tension in the springs will suffice, the blocks almost falling off by gravity. They sometimes stick when nearly worn down from the binding of the rag on to the flange of the wheel. But it is not really necessary to have a keep of any sort on the brake block to bite on the flange. The tread is quite flat and the distance between the blocks is firmly fixed, so there is no danger of their being forced outwards. Steel-tyred wheels are an exception to this, as the flange will soon become disproportionately large if the brake block does not rub on it.

Air Brakes are of no use on urban cars. They are too constantly in use, and are a fruitful source of flat wheels through the carelessness of motormen.

Slipper Brakes should always be fitted to cars running on gradients steeper than 1 in 12 or 15, where there is much traffic coming out of macadamised side streets. The wood blocks bite well on the rail, and can be adjusted to keep the car going down the gradient at a steady pace, the ordinary hand brake being used for stops.

Rheostatic brakes are condemned on account of the extra work thrown thereby on motors and resistances, the whole strain falling on the most expensive part of the equipment. Every car should, however, be fitted with an emergency brake, by which the motors can be reversed and short circuited; but there must be no intermediate notches, or the motorman will use this brake for service stops as well.

Electromagnetic Brakes come under a very different category to rheostatic. Here the braking effect is not by a large current, but by the large magnetising effect produced by a small current. The brake may either pull the ordinary brake blocks on to the wheels, or act by eddy currents or actual frictional contact on a special disc. But if a car is fitted with hand, slipper, and electric emergency brake, no other is necessary, no other being as good as each of these is in its own province.

Sanding gear is generally unsatisfactory, though it is difficult to overestimate the importance of this part of the equipment. What is wanted is a continuous and copious stream of sand directed to the proper place. There is an impression that it is only in greasy weather that trouble may be expected. But this is not so. The track can get very bad in a long drought—so bad, indeed, that a car running at eight or ten miles per hour will slide on practically unchecked for 100 or even 150 yards when the emergency brake is applied without sand, the wheels being almost locked. The ordinary hand brake is far more successful than a magnetic or rheostatic brake both under these conditions and in ordinary slippery weather, probably because it cleans the greasy film off the wheels. The position of the sand pedal should be selected carefully so as not to interfere with the motorman's control of the brake while sand is being applied; for, unless the brake handle is kept in the hand and the pressure eased from time to time, there is a great likelihood of the wheels skidding for long distances; and to work the brake thus it is necessary that the motorman's weight should be on his right foot, his left being free. The pumping of sand is a continuous business, and should be put to the free foot and the gong pedal to the right, for that is a momentary operation, not often required, and it can be done without the motorman shifting his weight.

Ventilation.—Ventilation of the interior is a much neglected detail. The small clerestory windows, even when all can be opened, are not sufficient, and ventilators in the doors make bad draughts if they are large enough to do any good. Four or six of the clerestory windows should be removed, and air extractors—of which there are several good types—should be substituted. All but two of these should be fitted with cut-off grids. Two should be left without them, for it is well to have a little compulsory ventilation. The others can be opened or shut according to the season and the number of passengers.

Motor Equipment.

Trolley Wheels.—If the ordinary V type of groove be used the wheel will run very smoothly on the wire, but will give a severe blow at the ears, where the diameter is increased by about 80 per cent. In the course of time the shock diminishes, but not without leaving its mark on the overhead work. Where the car is taking a heavy current the sparking is sufficient to burn away most of the sharp corners; but on the level or on a down gradient the ear is partly forced up from the wire, and partly worn away. If the wheel groove be made wide enough to take in the ears without shock, it runs noisily and unsteadily on the wire. The best form is a wide groove, with a shallow depression in it, equal to the diameter of the trolley wire and about half its depth. Graphite bushings should be oiled frequently; thus their life will be increased by about 40 per cent. Trolley wheels with grease or oil lubrication will run for long periods without attention, but so important a part of the equipment should have nightly examination.

Trolley Standards.—It is necessary that a trolley standard that is to run under all conditions should fulfil the two following requirements: (1) that the tension at the trolley head should be nearly constant, whatever the height of the wire; (2) that the trolley should swivel easily. To No. 1 may be added this: that the tension shall not decrease when the trolley head is at its lowest point. This is especially necessary in trolley standards for single-deck cars, for these frequently run under conditions where there is a range of 8 ft. in the height of the trolley wire, and if the head is sluggish in rising, it may give trouble by leaving the line, especially if there is a wide side reach. For No. 2 the standard must work on ball bearings, and arrangements must be made for lubricating the ball races. Standards with plain bearings give trouble on sharp curves which are taken with too few pull-off's. Easy means of adjusting the tension are necessary, also an adjustable stop for limiting the possible rise of the trolley head. Compactness is not so essential for single-deck cars, though it may be necessary in some special cases to limit the height of the standard when the boom is horizontal to 12 in. or 14 in., but it is very desirable on double deckers, especially when the trolley is placed centrally. It is well to fasten the trolley head lightly to the boom, so that in case of accident it is easily pulled off, without damaging standard or overhead work. The hood of the standard should be made slightly larger than it usually is at present, to permit the connection between the trolley cable and the car wiring to be made there instead of at the base. A door about 4 ins. by 6 ins. should be provided so that the connector can be got at for fastening and insulating. There need be no hinges—the door may be let in flush with the rest of the metal and kept in place by four ¼ inch counter-sunk set screws centred on the join. This arrangement will make it possible to change the boom or refasten trolley head and cable without lifting the whole standard. Care should be taken to insulate the boom well from the standard, and the standard itself should be earthed through two leakage lamps in series, one at each end of the car.

The method of fastening the trolley standard to the roof of double-

deck cars is rather primitive. The trolley plank, though it extends the whole length of the roof, and is screwed to every rafter, is usually only the same width as the base of the standard. It does very well when the trolley wire is always over the standard, but it is not a strong enough fastening when there is a wide side reach, especially if the trolley wire is at all slack. After some months' running under these conditions the screws begin to draw, and the standard and plank begin to sway. Then the white lead round it cracks and water finds its way down inside the roof. To prevent this, three or four strong irons, 3 ft. or 4 ft. long, should be screwed to the trolley plank and to the roof ribs, two perhaps under the base of the standard if the rafters will admit them, and two fore and aft of it. These offer no obstruction if they are made the same size as the wood strips on the roof of the car, and give the standard a firm fastening in every direction.

Car Wiring.—Bunching all the leads together in a cable hose is undesirable, and tee'd joints should be avoided. The leads may be looped, but they are inconveniently large unless they are paralleled at the controllers by a third wire, which causes a serious increase in the number of the leads. A system of many-cored cables is the best, all the leads in the same cable being braided in different colours. Where a tapping is required the cable should be cut and the ends sweated into the terminals of a connecting-box. Resistance leads are best looped, cables from both controllers coming up direct to the binding posts, which should be made a little longer for this purpose. The best place for the resistances is inside the car, under the seats. A sheet of asbestos laid over them will be quite sufficient to protect the seat from the heat, unless they are used for braking or speed regulation as well as starting. Then other means will be necessary for removing the heated air—such as an air extractor to suck it out through the double casement for the sliding door—or it can be used for heating the car.

Brush springs should be designed to give a more even pressure throughout their whole range, and should have plain ends, where they bear on the top of the brush. The continued pressure on a semi-circular end is apt to cause it to spread, so that it fouls the brush-holder as the brush wears down. The result is a loose brush, with sparking at the commutator and between brush and holder, frequently flashing over to the motor casing.

Inspection doors should be made of ample size, not only over the commutator but also in the lower half of the motor casing, to allow easy admittance for a long gauge to test the clearance between the armature and the lower pole pieces. Efficient drainage apertures should be made underneath the armature bearings, to insure that no waste grease or oil will find its way down inside the motor casing or on to the commutator.

NOTE ON AN OBSERVED EFFECT OF LIGHTNING DISCHARGE ON BIRDS IN MID-AIR.

Communicated by MR. LEONARD JOSEPH to, and reported by, W. LANGDON, President.

An interesting communication has been received from Mr. Leonard Joseph, A.M.I.E.E., who, writing from Zechliner Hütte, bei Rheinsberg i.d. Mark, on the 15th of December, 1901, relates that on the 9th of that month during a heavy storm, accompanied by thunder and lightning, a wild goose fell through the air and with a thud buried itself fairly deep in the sand.

On the abatement of the storm, at a distance of approximately a kilometre from the point at which the bird above referred to was picked up, another dead wild goose was found.

On a careful examination of the two birds, it was found that the only wounds upon them were "a narrow but direct opening about 3 c.m. long" on the *back* of the neck of the first found bird, and a small puncture "at a point where the neck joins the body" on the second bird.

Excepting in the immediate neighbourhood of these wounds the bodies and feathers of the birds were uninjured. The feathers at these points appeared and smelt singed. Both birds proved perfectly fit for the table.

During the storm five flashes of lightning only were observed. Judged by the position in which the birds were found, Mr. Joseph is of opinion their flight was in opposite directions, the wounds in each instance being instantaneously fatal.

JOURNAL

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The Three Hundred and Seventy-second Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 13th, 1902—Mr. R. KAYE GRAY, Vice-President, in the Chair.

The minutes of the Ordinary General Meeting held on January 23rd, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members :—

Ivon Braby.
Percival John Pringle.
Mark Ruddle.

From the class of Associates to that of Members :—

William Thom.

From the class of Associates to that of Associate Members :—

Arthur Armitage.
Edward Arthur Barker.
Malcolm Henry Butcher.
Walter Claypoole.
Thos. Morland Colson.
Frederick Robert Connell.
Harry Richmond Mott.
Edward J. Saner.

From the class of Students to that of Associates :—

Vero Marshall Allen.
R. F. P. Blennerhassett.
John Geo. Bruce.
John Campbell Callander.
Frederick H. Clough.
Thos. C. Cunningham.
Robert Grigg.
Herbert B. Johnson.
Hammond L. E. Kennard.
Wm. Mackintosh.
Wm. Turner Marsden.
Edward D. Morgan.
Chas. Ernest Newton.
Ayton Herbert Read.
Wm. Spencer.
Geo. Stamp Taylor.
Chas. Wm. Wood.

Messrs. Claypoole and J. T. Morris were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received from Section VIII. (Gas) International Engineering Congress, Glasgow; The Ministry of Commerce, Paris; and Messrs. A. Heyland and F. C. Raphael; to the *Building Fund* from Messrs. H. G. Andrews, W. J. Bishop, S. L. Brunton, H. C. Channon, E. Coates, R. F. Fuller, W. McGeoch, M. M. Gillespie, J. Kynoch, A. P. Pyne, S. C. Smith; and to the *Benevolent Fund* from Messrs. W. J. Bishop, M. M. Gillespie, C. C. Paterson, A. Sommerville, F. H. Webb, to whom the thanks of the meeting were duly accorded.

The CHAIRMAN: I have now very much pleasure in asking Professor Barrett to read the paper which he has been good enough to prepare for our acceptance. I may mention, in asking him to do so, that he has, at very considerable inconvenience to himself, come from the sister island to lay his views before us, and I am sure we are very much indebted to him for it.

RESEARCHES ON THE ELECTRICAL CONDUCTIVITY AND MAGNETIC PROPERTIES OF UPWARDS OF ONE HUNDRED DIFFERENT ALLOYS OF IRON.

By W. F. BARRETT, F.R.S. Member, Prof. of Physics, Royal College of Science for Ireland and W. BROWN, B.Sc., Assoc. Member, Assistant Physicist in the same College, and R. A. HADFIELD, M.Inst.C.E., Managing Director, Hecla Steel Works.

INTRODUCTION.

For several years past the authors have been engaged in the investigation of the physical properties of an extensive and unique series of alloys of iron prepared with great care at the Hecla Steel Works, Sheffield.[1]

In the preparation of these specimens a great variety of different alloys of iron were made and cast into ingots. Many of these ingots, after examination, were rejected owing to the difficulty of getting good castings or the impossibility of forging and then rolling the specimens.[2]

[1] See *Scientific Transactions of the Royal Dublin Society*, January, 1900, vol. vii. series 2, part 4; joint paper by Barrett, Brown, and Hadfield.

[2] Several of the castings were planed, and where preliminary tests of conductivity made by us showed that they were not homogeneous they were rejected.

There remained 110 specimens suitable for this investigation, which were forged into bars, and these bars, after being heated to a bright red (about 900° C.), were rolled into rods of nearly circular cross section, about half a centimetre (0·2 inches) in diameter (No. 5 B.W.G.), and cut into lengths of 106 cms. (42 inches). After being straightened, the rods were tested for electrical conductivity, and many of them for magnetic permeability, as they stood, *i.e.*, in the ordinary rolled or unannealed condition. The rods were then returned to Sheffield and very carefully annealed, being heated to about 1,000° C., the cooling (in an E. and W. position) taking 100 hours, about four days and nights. They were returned to Dublin, and the electrical conductivity and magnetic properties of the whole series carefully determined by Mr. Brown and myself in this annealed condition. Later on we propose to repeat the experiments on the rods when hardened, after further tests on other physical properties of these alloys in their present annealed condition have been concluded.

The following is a complete list of the specimens tested in the form of rods and wires :—

CLASS 1.	Alloys of iron containing varying proportions of *one* other element	59	specimens
„ 2.	Ditto, ditto, *two* other elements	44	„
„ 3.	Ditto, ditto, *three or more* elements	7	„
	Total	110	

CLASS I.

Group.	Description.	No. of specimens having varying percentages of the added element.	
1.	Carbon-iron alloys	13	varieties.
2.	Manganese „ „	18	„
3.	Nickel „ „	12	„
4.	Tungsten „ „	4	„
5.	Aluminium „ „	3	„
6.	Silicon „ „	2	„
7.	Chromium „ „	3	„
8.	Copper „ „	4	„
	Total	59	

CLASS II.

Group.	Description.	No. of specimens having varying percentages of the added element.
9.	Nickel-copper iron alloys	1 variety.
10.	Nickel-chromium " "	6 varieties.
11.	Nickel-silicon " "	5 "
12.	Nickel-manganese " "	9 "
13.	Manganese-chromium iron alloys	4 "
14.	Manganese-tungsten " "	4 "
15.	Manganese-silicon " "	2 "
16.	Manganese-copper " "	2 "
17.	Chromium-aluminium " "	4 "
18.	Chromium-silicon " "	3 "
19.	Chromium-copper " "	1 "
20.	Chromium-tungsten " "	1 "
21.	Aluminium-copper " "	1 "
22.	Aluminium-silicon " "	1 "
	Total	44

CLASS III.

23.	Cobalt-manganese-silicon iron alloys ...	2 varieties.
24.	Nickel-iron-copper " " ...	1 "
25.	Chromium-tungsten-copper " " ...	1 "
26.	Chromium-manganese-silicon iron alloys...	1 "
27.	Nickel-manganese-aluminium-silicon " "	1 "
28.	Copper-manganese-chromium " "	1 "
	Total	7

A chemical analysis of the whole of these alloys was made in the laboratory attached to the Hecla Works, Sheffield, and the percentage composition of each is given in the tabular statement later on. The present paper is divided into four parts. Part I. deals with the electric conductivity of these alloys; Part II. with their magnetic properties; Part III. describes a series of practically non-magnetic alloys of iron; and Part IV. gives the results obtained with two alloys containing nearly 3 per cent of non-magnetic elements which nevertheless are, within certain wide limits of induction, more magnetic than the purest commercial iron obtainable (Swedish charcoal iron, containing 99·89 per cent. of iron), all being in the same physical state as regards annealing.

PART I.

ELECTRIC CONDUCTIVITY.

The conductivity of the rods was determined by the potential method,[1] the fall of potential over a known length of the rod under experiment being compared with the fall over a corresponding length of a standard copper or iron rod. The homogeneity of each specimen was tested by taking the fall of potential over one-half and one-quarter the length of each rod as well as over the whole length; the galvanometric deflections being found proportional to the length, except in the cases of two or three specimens, which were not in quite the same physical state throughout. The length of each rod having been determined, its volume, and hence by calculation its sectional area, was carefully measured by water displacement. A long glass tube, closed at one end, was employed for this purpose, the tube being 1 cm. diameter and graduated to tenths of a c.c.[2]

Since our memoir in the *Trans. R. D. S.* was published we have made a new series of diagrams showing the electric conductivity of the rods in the annealed condition, the measurements being taken as above described. These diagrams are here given, Fig. 1 (p. 688) showing the electric conductivity and Fig. 2 the specific electric resistance of those alloys of iron contained in Class I., *i.e.*, when a single element in varying proportions is alloyed with iron. In Fig. 1 the ordinates express the conductivity, Matthiessen's pure hard copper being taken as 100, and the abscissæ give the percentage of the other elements alloyed with the iron. In Fig. 2 the abscissæ are the same, but the ordinates express the specific resistance in microhms per c.c. We regret that it is impossible to represent by diagrams on a plane surface the results obtained with varying percentages of two or more elements added to iron. These results are shown in tabular form further on, the specific resistances being calculated.

[1] Details of these experiments are given on pp. 70 and 71 of our paper in the *Transactions of the Royal Dublin Society* for 1900.

[2] The diameter of each rod was in the first instance determined at six different points by means of a micrometer screw, but on account of the cross section of the rods not being quite circular the method of water displacement was finally adopted. This method of measurement gave such excellent results that the conductivities of the whole of the rods were re-determined after using this method.

The standard with which the conductivity of the rods was compared was a specimen of pure copper obtained from Kelvin and White, of Glasgow; the conductivity of this standard had been determined with care in the Physical Laboratory of Glasgow University and found to be 101·01, Matthiessen's hard-drawn pure copper standard being taken as 100. In addition to the foregoing, a standard was made of the purest commercial iron in the form of a rod 104 cms. ong, carefully turned to a uniform diameter throughout ts length; the sectional area of the rod being 0·1874 sq. cms., about the same as the rest of the specimens.

A sample of this standard iron was drawn into wire of the same diameter as the copper standard (0·124 cms.) and the relative conductivity of the iron and copper wires directly determined and also their specific resistances per c.c. The specific resistance was found to be 10·47 microhms per c.c. for the iron wire, and 1·721 for the copper, both at 18° C. The conductivity of the iron deduced from these values is 16·44. Comparing the conductivity of the standard iron *rod* with the iron *wire*, the former was found to be 16·5 and the latter 16·4, Matthiessen's copper being taken as 100; this slight difference between the iron rod and iron wire being due to some variation in hardness in the two specimens, which had not been specially annealed. When the wire was carefully annealed its conductivity rose to 16·78; copper, as before, being 100.

Hence by multiplying the conductivity of any specimen, in terms of *copper*, by 100, and dividing by 16·78, we obtain the conductivity in terms of our standard *annealed iron as* 100. As, however, it is often more convenient to express the results as resistances, we can find the *specific resistance of any specimen* in microhms per c.c. by multiplying the specific resistance of our standard copper (1·721) by 100 and dividing by the conductivity of the specimen in terms of copper, the ratio of the respective resistances being inversely as the ratio of their conductivities. This has been done in the tabular statements which follow.

It will be observed that the specific resistance here given for our copper and iron standards is slightly higher than the number usually found in tables of physical constants for these bodies at the corresponding temperature. Much, of course, depends on the physical state as well as chemical

purity of the specimens. The chemical analysis of our standard iron is as follows :—

ANALYSIS OF STANDARD IRON MARKED S. C. I.

Iron	99·89
Carbon	0·028
Silicon	0·07
Sulphur	0·005
Phosphorus	0·004
Manganese	trace
	99·997

So that our standard iron has only about one-tenth of 1 per cent. of impurities, and is therefore a remarkably good specimen of Swedish Charcoal Iron. The copper was *hard drawn* electrolytic copper, and, as we have already said, was found in Lord Kelvin's laboratory to be 1·01 per cent. higher conductivity than Matthiessen's pure hard-drawn copper. The data supplied (from the same laboratory) with this wire were as follows :—

Diameter...	0·12404 cm.
Sectional area	0·012084 sq. cms.
Weight per metre ...	10·7689 grammes.
Density	8·9117
Resistance per metre ...	0·014245 { Board of Trade Ohms at 18·1° C.
Temperature variation ...	0·004 per Ohm. per 1° C.

The specific resistance deduced from the above is 1·721 microhms per c.c. at 18·1° C. Our own direct measurements of this wire gave almost exactly the same value for its specific resistance.[1]

The accompanying table gives the values we have found for the conductivity of the first series of specimens, Matthiessen's copper being taken as 100. The last column gives the corresponding values of the specific resistance in

[1] The value now adopted for Matthiessen's pure hard-drawn copper is 1·626 microhms per c.c. at 0° C. The high temperature coefficient of copper raises this value to 1·7437 at 18·1° C. This number reduced 1·01 per cent. (which represents the conductivity of our specimen of copper) becomes 1·7261, closely agreeing with the number we found by direct measurement.

TABLE I.

Group.	Maker's Mark.	Percentage Composition.				Electrical Conductivity.		Specific Resistance.
		Fe.	**C.**	**Mn.**	**Si.**	Iron = 100.	Copper = 100.	
Carbon Series ... (A.)	S.C.I.	99·89	0·028		0·07	100	16·8	10·2
	B.	99·71	·03	0·036	·14	93·4	15·7	10·9
	L.S.S.	99·72	·05	·18	·02	90·4	15·2	11·3
	1166	99·50	·14	·20	·08	80·4	13·5	12·7
	1392 H	99·02	·78	·10	·10	70·3	11·8	14·6
	,, I	98·86	·83	·25	·06	67·3	11·3	15·2
	,, B	98·78	·84	·18	·20	63·7	10·7	16·1
	,, A	98·66	·85	·32	·17	62·5	10·5	16·4
	,, L	98·42	1·09	·32	·17	58·9	9·9	17·4
	,, G	98·51	1·23	·14	·12	58·3	9·8	17·6
(B.)	611	98·35	·58	·58	·49	49·4	8·3	20·7
	613	97·93	1·00	·58	·49	45·8	7·7	22·3
	614	97·67	1·25	·62	·46	43·5	7·3	23·6
Manganese Series ... (A.)	48	99·30	·20	·50		70·8	11·9	14·5
	4147	98·76	·24	1·00		43·5	7·3	23·6
	53	97·34	·41	2·25		35·1	5·9	29·2
	1379 B	96·29	·08	3·50	·13	34·5	5·8	29·7
	39	95·64	·36	4·00		35·7	6·0	28·7
	34	94·89	·36	4·75		34·9	5·86	29·4
	32	94·53	·32	5·15		27·4	4·6	37·4
	1323 C	94·46	·15	5·40		30·4	5·1	33·7
	1338 B/2	86·74	·26	13·00		16·7	2·8	61·8
	1379 D/2	84·64	·15	15·20		15·8	2·65	64·9
(B.)	1381	95·41	·78	3·81		23·2	3·9	44·1
	945 A	91·80	1·20	7·00		18·5	3·1	58·7
	1379 D	89·11	·16	10·10	·63	16·1	2·7	63·7
	1310 B	86·84	1·66	11·50		16·7	2·8	61·5
	1010	85·77	1·23	13·00		16·1	2·7	63·7
	30	83·25	1·50	15·25		15·5	2·6	66·2
	598	80·96	1·54	18·50		14·9	2·5	69·0

TABLE I. (*continued*).

Group.	Maker's Mark.	Percentage Composition.					Electrical Conductivity.		Specific Resistance.
		Fe.	**C.**	**Mn.**	**Ni.**	**Si.**	Iron = 100.	Copper = 100.	
Nickel Series ... (A.)	1287 D	97·01	0·14	0·72	1·92	0·21	50·0	8·4	20·44
	„ E	95·14	·19	·65	3·82	·20	42·8	7·2	24·6
	„ I	87·28	·18	·93	11·39	·22	28·6	4·8	35·8
	„ K	78·97	·19	·93	19·64	·27	26·2	4·4	39·0
	„ L	74·03	·16	1·00	24·51	·30	22·6	3·8	45·1
(B.)	1449 A	67·08	·70	·82	31·40		11·9	2·0	80·0
	1420 A	98·25	·75	1·00			38·1	6·4	26·9
	„ B	97·50	·50	1·00	1·00		36·3	6·1	28·0
	1397 A	99·16	·22	·18		·44	60·1	10·1	17·0
	„ B	98·65	·26	·18	·58	·33	57·3	9·6	17·9
	1447 A	85·49	·81	·61	12·70	·39	23·2	3·9	44·1
	„ B	85·75	·98	·61	12·10	·56	22·6	3·8	45·3
	1449 E	67·90	·60	1·50	30·00		11·6	1·95	88·2
					W.				
Tungsten Series ...	1294 F	98·73	·16	·11	1·00		67·9	11·4	15·1
	„ H	95·94	·28	·28	4·50		57·3	9·6	18·0
	„ I	91·92	·38	·20	7·50		53·0	8·9	19·2
	„ L	83·46	·76	·28	15·50		38·1	6·4	26·6
					Al.				
Aluminium Series ...	1167 D	98·98	·17		0·75	·10	46·4	7·8	22·0
	„ H	97·33	·24		2.25	·18	26·2	4·4	39·0
	„ I	94·08	·22		5·50	·20	14·9	2·5	70·0
Silicon Series ...	898 E	97·30	·20			2·50	24·4	4·1	42·1
	„ H	94·24	·26			5·50	15·7	2·6	65·2
					Cr.				
Chromium Series ...	993	97·10	·90		2·00		42·3	7·1	24·2
	1177 I	97·32	·43		3·25		41·1	6·9	24·9
	„ N	89·45	1·09		9·50		26·8	4·5	38·2
					Cu.				
Copper Series ...	1264 A	97·37	·68	·36	1·59		68·4	11·5	14·9
	„ B	96·59	·59	·32	2·50		70·8	11·9	14·4
	1263 C	95·92	·17	1·04	2·87	**Al.**	58·3	9·8	17·4
	1149 A	95·05	·04	·16	3·75	1·00	48·2	8·1	21·0

microhms per c.c., calculated as mentioned above. The temperature throughout was that of the air, about 18° C. Each specimen was identified by the particular marks stamped on it by the manufacturer, as given in column 1[1]. The succeeding columns give the percentage composition of each specimen, the iron being estimated by difference.[2] In spite of the care taken in the manufacture of these alloys to reduce the impurities to a minimum, it will be observed that a certain percentage of carbon and of manganese is present in all the specimens. This is unavoidable in the ordinary process of manufacture; but we believe these impurities are present in smaller quantities than in any other considerable collection of iron alloys yet made.

As there were a large number of specimens in the first three groups we have put together those with the smaller amount of impurity (carbon or manganese, or both, as the case may be) in subdivision A. and the others in B.

The foregoing results are graphically represented in Figures 1 and 2, only the low carbon specimens being plotted, except in the case of the manganese group, where both are given.

Passing on to the alloys in Class II. which contain two elements added to iron, we have the results given in Table II.

The discussion of these results need not occupy us here;[3] it will be sufficient to point out that a similar effect on conductivity is produced by the different elements when more than one is present in the alloy as was observed previously when one only was added to iron. In fact, the rate of increase of specific resistance produced by successively adding 1 per cent. of, say, aluminium to iron will be found almost the same as the rate deduced from similar additions of aluminium to a composite chromium-aluminium-iron alloy, and so on with other of these alloys.

The electric conductivity of the still more composite alloys in Class III., where three or more elements are added to iron, is shown in Table III.

Many of these alloys were drawn into wire, and their

[1] These marks afford an indication of a consecutive series of castings, *e.g.*, 1392 H, I, etc., or of castings made at different periods, *e.g.*, 611, 613, 614, etc.

[2] In the first three specimens in Table I. a complete analysis was made, and the small amount of phosphorus and sulphur found (not shown in the table) reduces the percentage of iron to that given in the table.

[3] See our paper in *Trans. R. D. S.*, 1900, p. 87 to p. 99.

specific resistance and also their increase in resistance per ohm per 1° C. between 0° C. and 150° C. determined in the ordinary way. When the wires were drawn from the same batch of castings as the rods, the specific resistance directly determined was practically the same as that deduced from the conductivity of the corresponding rods. These results are given in Table IV.

The highest electrical resistance of any known metallic wire, commercially useful, has been found in some of these composite iron alloys. Thus an alloy of 25 per cent. of nickel and 5 per cent. of manganese has a specific resistance of 97·5 microhms and a comparatively low temperature coefficient. This alloy is easily drawn into wire, and appears to undergo but little change in heating, and is not an expensive product. It has also some remarkable thermo-electric properties which have been investigated by one of us.[1] Many of these nickel-manganese iron alloys were made by Mr. Hadfield many years ago, and their specific resistance and temperature coefficient were determined by us in 1895. Among these was the alloy containing 15 per cent. of nickel and 5 per cent. of manganese, originally called Rheostene, now known as Resista, and the physical properties of this material were fully investigated by us in 1895. Since then various makers have given other names to these alloys and they are to be had on the market. For six years we have had the whole of the resistance coils used in our electric installation and lecture theatre in the Royal College of Science made of rheostene, and no depreciation of the material has been noticed.[2]

Why the conductivity of a metal is so much reduced by a small quantity of another element alloyed with it and why the effect produced by these elements should vary in the order we have found are problems that await explanation. It is, however, possible that some light may be thrown by this investigation upon this difficult question. A series of experiments are in progress, and will shortly be published, in which the thermal conductivities of these alloys are being measured. We have already determined the relative thermal conduc-

[1] See paper by Professor Barrett in *Trans. R. D. S.*, Jan., 1900.

[2] Some users have complained of rheostene that it becomes brittle and perishes. Under certain circumstances we have noticed this is the case with thin wire of this material.

TABLE II.

Group.	Maker's Mark.	Fe.	C.	Mn.	Ni.	Conductivity. Iron = 100.	Conductivity. Copper = 100	Specific Resistance.
Nickel-Manganese Series ...	1420 B	97·50	0·50	1·00	1·00	35·7	6·0	28·7
	1254 C	91·68	·57	3·75	4·00	21·7	3·7	47·5
	1339	88·22	1·21	8·00	2·57	14·6	2·5	70·2
	1313 C	79·35	1·40	10·25	9·00	13·7	2·3	74·7
	1109 D	80·16	·80	5·04	14·55	12·2	2·05	83·0
	1414 A	75·36	·60	5·04	19·00	12·5	2·1	82·0
	" B	69·36	·60	5·04	25·00	11·5	1·93	89·2
	1449 A	67·08	·70	0·82	31·40	11·9	2·00	86·0
	" E	67·90	·60	1·50	30·00	11·6	1·95	88·2
				Cr.				
Nickel-Chromium Series ...	1286 A	96·25	·25	0·75	2·75	42·8	7·2	23·9
	1480	95·10	·90	2·00	2·00	40·4	6·8	25·3
	1286 C	95·44	·31	1·75	2·50	36·9	6·2	27·7
	1327 C	94·14	·86	1·75	3·25	35·7	6·0	28·5
	1210 D	92·59	·41	4·50	2·50	29·2	4·9	35·1
	1450	85·11	·64	2·01	12·24	19·7	3·3	52·1
				Cr.	**Mn.**			
Manganese-Chromium Series ...	1274 A	90·85	1·15	5·00	3·00	21·4	3·6	47·8
	1430	86·69	1·30	8·92	3·09	27·9	4·7	36·6
	1233 A	86·82	1·36	9·22	2·60	16·1	2·7	63·7
	620	78·12	·88	3·50	17·50	14·9	2·5	68·8
				Cu.	**Ni.**			
Nickel-Copper	1252 B	91·32	·18	2·75	5·75	26·8	4·5	37·4
				Cu.	**Mn.**			
Manganese-Copper Series ...	1240	96·25	·25	1·50	2·00	40·4	6·8	25·2
	1260 A	88·61	·64	2·75	8·00	19·7	3·3	51·8
					Cr.			
Chromium-Copper	1255 A	91·60	·85	1·80	5·75	32·7	5·5	29·2

TABLE II. (*continued*).

Group.	Maker's Mark.	Fe	C.	Ni.	Mn.	Si.	Conductivity. Iron = 100.	Conductivity. Copper = 100.	Specific Resistance.
Nickel-Silicon Series	1447 A	86·10	·81	12·70	·61	0·39	23·8	4·0	43·0
	„ B	86·37	·97	12·10	·61	·56	22·6	3·8	45·0
	1103 A	94·37	·38	3·25		2·00	23·2	3·9	44·0
	1102 A	96·21	·79	1·00		2·00	20·3	3·4	50·5
	1103 C	93·03	·22	3·50		3·25	17·9	3·0	57·4
Manganese-Silicon ...	1379 D	89·13	·16		10·08	·63	16·7	2·8	61·1
	601	93·35	·40		2·00	4·25	14·9	2·5	68·4
				Cr.					
Chromium-Silicon ...	518	96·24	·76	2·00		1·00	32·1	5·4	31·8
	517	95·34	·86	2·00		1·80	23·3	3·9	44·0
	1185 F	93·71	·54	3·50		2·25	20·3	3·4	50·5
				W.					
Manganese-Tungsten Series	687	94·10	·40	3·25	2·25		36·9	6·2	27·7
	683	85·23	1·52	10·00	3·25		33·3	5·6	31·3
	1343 B	86·61	1·08	2·11	10·20		15·5	2·6	65·8
	„ A	84·71	1·34	2·85	11·10		14·9	2·5	68·4
				Al.	**Cr.**				
Chromium-Aluminium Series	1178 B	97·29	·21	·75	1·75		36·3	6·1	28·0
	1179 B	95·04	·46	1·00	3·50		22·6	3·8	45·0
	1178 D	95·82	·18	2·50	1·50		20·3	3·4	50·3
	„ E	93·78	·22	4·50	1·50		14·9	2·5	68·4
Silicon-Aluminium ...	803	96·58	·67	·50		2·25	23·8	4·0	43·0
					Cu.				
Copper-Aluminium ...	1149 A	95·21	·04	1·0	3·75		48·2	8·1	21·1

TABLE III.

Group.	Maker's Mark.	Percentage Composition.					Electrical Conductivity.		Specific Resistance.
		Fe.	**C.**	**Mn.**	**Co.**	**Si.**	Iron = 100.	Copper = 100.	
Manganese-Cobalt-Silicon ...	1209 C	96·31	·25	1·00	1·80	·64	44·1	7·4	23·2
	" F	90·88	·52	0·80	7·00	·80	33·3	5·6	30·7
Manganese-Chromium-Silicon	608	90·93	1·32	4·25	**Cr.** 2·00	1·50	19·7	3·3	52·1
Manganese-Copper-Nickel ...	1424 B	76·58	·83	5·90	**Cu.** 2·25	**Ni.** 14·44	12·8	2·15	80·0
	1261 A	92·53	·17	1·50	2·90	2·90	41·1	6·9	24·9
Manganese-Nickel-Aluminium	1411 *	77·26	·43	5·30	**Al.** 2·30	14·10	21·4	3·6	47·8
Chromium-Copper-Tungsten	1249 A	93·77	·48	**Cr.** 1·75	**Cu.** 2·00	**W.** 2·00	32·7	5·5	31·5
Chromium-Tungsten ...	1189 B	97·00	·25	·75		2·00	57·3	9·6	18·0

* This specimen also contains 0·61 of Silicon.

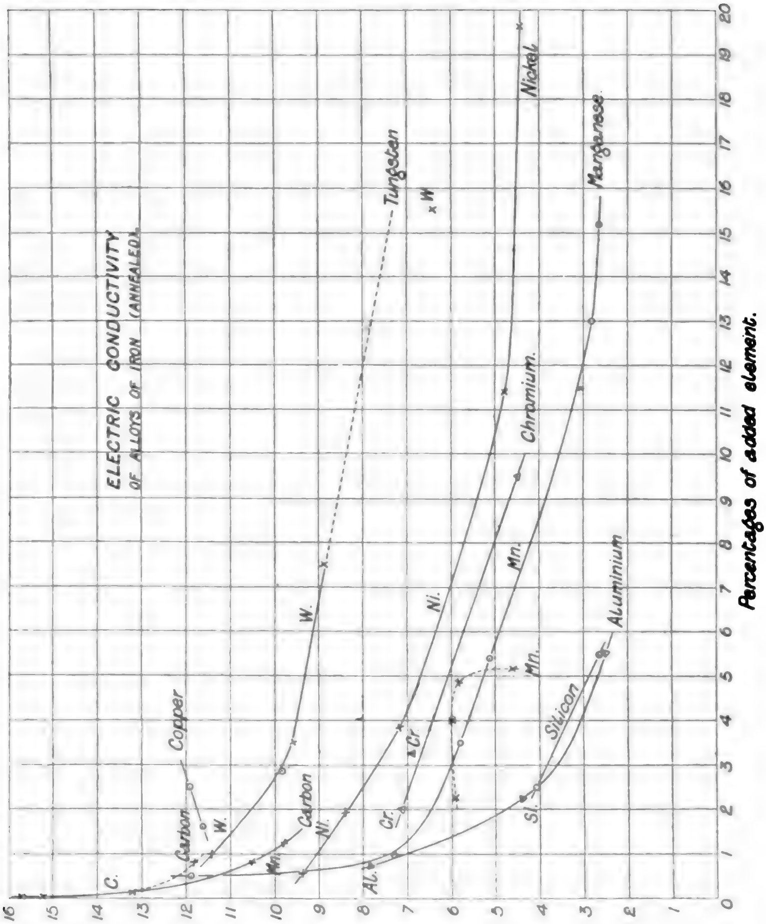
TABLE IV.

Specific Resistance and Temperature Co-efficient of Annealed Alloys of Iron drawn into Wire

(compared with the Specific Resistance deduced from the Conductivity of the same Alloys in the form of Rods.)

Maker's Mark.	Percentage Composition.	Specific Resistance. Microhms per c.c.		Temperature Co-efficient.
		Rod.	Wire.	
S. C. I.	Fe. 99·89 ; C. 0·028 ; Si., 0·07 ; S. and P., 0·009 (pure commercial iron) ...	10·5	10·47	0·006
1264 B	„ 96·59 ; „ 0·59 ; Cu., 2·5 ; Mn., 0·32	14·4	13·5	0·00457
„ A	„ 97·36 ; „ 0·68 ; „ 1·6 ; „ 0·36	14·9	13·9	0·00418
1236 C	„ 95·93 ; „ 0·17 ; „ 2·9 ; „ 1·00	17·4	16·2	0·00366
1149 A	„ 95·26 ; „ 0·04 ; „ 3·7 ; Al., 1·00	21·0	20·8	0·00280
1249 A	„ 93·77 ; „ 0·48 ; „ 2·0 ; W., 2·00 ; Cr., 1·75	31·3	31·6	0·00204
1167 I	„ 94·26 ; „ 0·22 ; Al., 5·5 ; Si., 0·2	70·0	74·6	0·00063
1420 B	„ 97·50 ; „ 0·50 ; Ni., 1·00 ; Mn. 1·00	28·7	28·6	0·00150
1109 D	„ 79·70 ; „ 0·80 ; „ 14·50 ; „ 5·0	83·0	83·0	0·00109
1414 A	„ 75·40 ; „ 1·00 ; „ 19·00 ; „ 5·0	...	90·6	0·00104
„ B	„ 69·40 ; „ 1·18 ; „ 25·00 ; „ 5·0	...	97·5	0·00085
1449 A	„ 67·48 ; „ 0·70 ; „ 31·00 ; „ 0·82...	86·0	86·5	0·00090
„ E	„ 67·90 ; „ 0·60 ; „ 30·00 ; „ 1·50	88·0	89·0	0·00077

tivity of upwards of forty of these alloys, and in every case the electric and thermal conductivities go hand in hand; the causes that diminish the electric conductivity would therefore also appear to diminish the thermal conductivity.

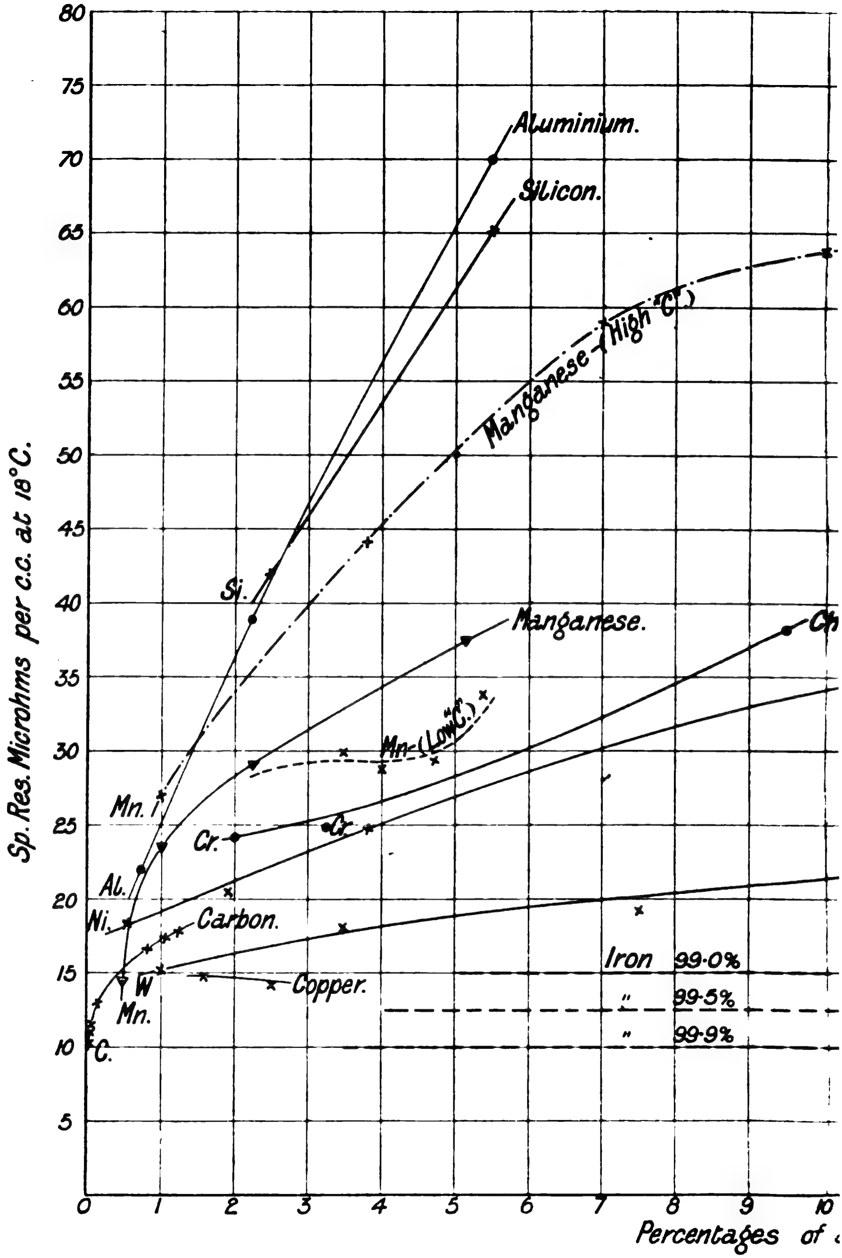


Conductivity, Pure Copper = 100.

FIG. 1.

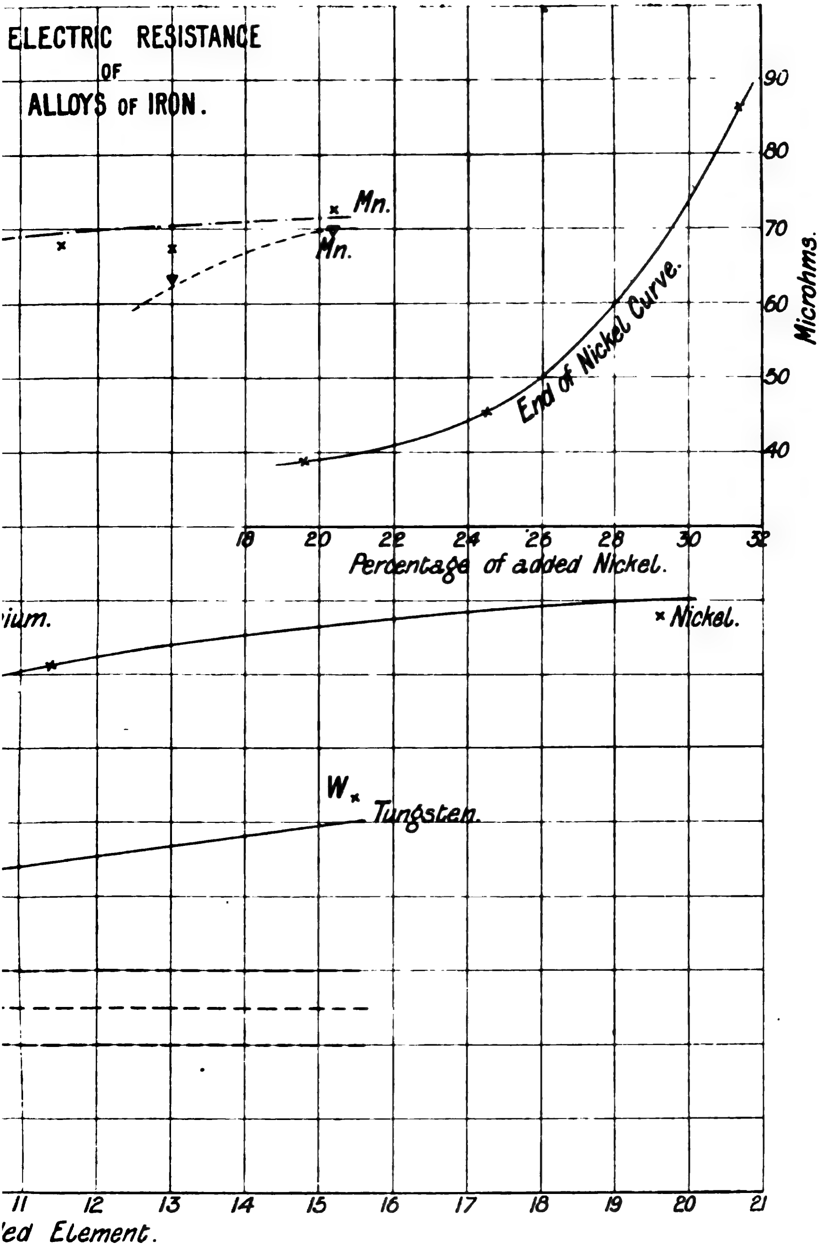
NOTES ON PART I. BY W. F. B.

(1) The results given in the preceding Part show that the conductivity of iron is in all cases *diminished* by alloying it with another metal, even though that metal be itself a better conductor than iron, except perhaps in the case of an alloy of iron and copper. In the case of the



Sp. Res. Microhms per c.c. at 18°C.
Aluminium.
Silicon.
Manganese (High "C")
Si.
Manganese.
Ch
Mn. (Low "C")
Mn.
Cr.
Cr.
Al.
Ni.
Carbon.
W
Mn.
Copper.
C.
Iron 99·0%
" 99·5%
" 99·9%
Percentages of

Fi



ELECTRIC RESISTANCE
OF
ALLOYS OF IRON.
Mn.
Mn.
End of Nickel Curve.
Microhms.
90
80
70
60
50
40
18
20
22
24
26
28
30
32
Percentage of added Nickel.
ium.
Nickel.
W
Tungsten.
11
12
13
14
15
16
17
18
19
20
21
ed Element.

copper-iron alloys the specimens at our command were very few and contained variable amounts of impurity. As will be seen from Table I., the only specimens in this group that are at all comparable are 1264 A and B, the latter containing about 1 per cent. more copper than the former, with a little higher conductivity, a difference which may be accounted for by the slightly less carbon and manganese impurities it contains, though both have high carbon. If we compare 1264 A with an ordinary steel containing nearly the same carbon, but no copper—such as 1392 H in Group I.—the conductivity of both is practically the same.

(2) The foregoing results also show that reduction of conductivity produced by alloying iron with another metal is not due to the greater specific resistance of the added metal. On the contrary, an iron alloy of *very high* specific resistance is produced by adding to iron an element of *much lower* specific resistance than the iron itself. In fact, the conductivity of the resultant alloy appears to have no connection with the conductivity of the constituents of the alloy. Thus, if we compare an aluminium-iron alloy with a corresponding percentage nickel-iron alloy, the former is a far worse conductor than the latter, albeit pure aluminium is upwards of three times *better* a conductor than pure iron, whereas nickel is a slightly *worse* conductor than iron. Taking an alloy of 2½ per cent. aluminium with iron and a similar nickel-iron alloy, Table V. shows the respective conductivities compared with pure aluminium and nickel, the nearest whole numbers only being given.

TABLE V.

	Conductivity.
Mathiessen's pure copper	100
Commercially pure aluminium	58
" " iron	17
" " nickel	12
Alloy iron + 2½ % nickel	8
" " + 2½ % aluminium	4

An inspection of Figs. 1 and 2 shows that of all the alloys we have examined the addition of *tungsten* to iron reduces the conductivity the least. I can find no record of the conductivity of this element having been determined,

nor of chromium, manganese, nor silicon, and should be glad if any one could give us information on this point.

(3) The profound effect on the conductivity of iron produced by the presence of small quantities of carbon is strikingly shown in Fig. 1. In fact, other things being equal, the conductivity of a specimen affords a rapid and simple method of estimating the amount of carbon present in a sample of steel, by an inspection of the curve in Fig. 1. The rolled and annealed specimens of carbon-iron alloys at our disposal did not contain more than 1¼ per cent. of carbon, so that we cannot carry the carbon curves beyond this point.

(4) Figs. 1 and 2 also demonstrate that the greatest reduction of conductivity, for a given percentage of the added element, is produced by the *first* increments of the element added. This is also shown in Table VI. below. As the percentage increases, *i.e.*, as the alloy becomes richer, the effect of corresponding increments—so far as the electric conductivity is concerned—becomes less, and in the case of the more highly resisting alloys, such as nickel and manganese, the difference between the conductivity of a 13 and 18 per cent. alloy is hardly perceptible. In a word, the curves fall steeply and tend to become asymptotic when the amount of alloy is largest and the conductivity is reduced to a certain low value.

TABLE VI.

APPROXIMATE SPECIFIC RESISTANCE OF IRON ALLOYS AT DIFFERENT PERCENTAGES OF THE ADDED ELEMENT NAMED IN FIRST COLUMN.

Alloy of Iron with	Percentage of Added Element.				
	1 per cent.	2 per cent.	3 per cent.	4 per cent.	6 per cent.
Tungsten	15·5	16·5	17·2	18·0	18·5
Nickel	19·0	21·0	23·0	25·0	27·0
Chromium	...	...	24·0	26·5	29·0
Manganese	23·5	28·0	31·0	34·0	39·0
Silicon	...	...	46·0	53·5	69·0
Aluminium	27·0	38·0	48·0	57·0	74·0

The effect thus produced on the transmission of *electricity* through an alloy of growing richness is therefore analogous to the effect produced on the transmission of white *light* through a medium which is tinted with increasing quantities of colouring matter, the first additions of the colour producing the greatest selective absorption.[1]

(5) Upon referring to Fig. 2, the resistance of specimens of the best commercial iron containing from 99·97 to 99·5 of pure iron is shown in the horizontal dotted lines. Taking the difference between the ordinates given by these specimens and the ordinates of the various alloys at any given percentage of added element, we obtain the increase of specific resistance produced by the addition of that element to iron. To obtain comparable results the percentage of carbon and other impurities in the alloy should be the same as in the specimen of iron with which it is compared. By referring to Table I. this can be found. Making the subtraction necessary in each case, we get the following results for the increase in specific resistance produced by the addition of 2, 4, and 6 per cent. of the following substances to commercially pure iron :—

TABLE VII.

INCREASE IN SPECIFIC RESISTANCE PRODUCED IN IRON OF CORRESPONDING PURITY BY ALLOYING IT WITH VARIOUS PERCENTAGES OF THE ELEMENTS NAMED.

Alloy of Iron with	2 per cent.	4 per cent.	6 per cent.	
Tungsten...	4·0	5·5	6·0	Microhms per c.c. at 18° C.
Nickel ...	6·5	10·0	12·5	,, ,, ,,
Chromium	...	12·0	14·0	,, ,, ,,
Manganese	15·0	21·0	26·0	,, ,, ,,
Silicon ...	...	41·0	55·5	,, ,, ,,
Aluminium	25·5	44·5	61·5	,, ,, ,,

[1] If this were anything more than a mere analogy, *i.e.*, if there was any selective absorption of an electric current, as there is of composite *radiation* —whether luminous, thermal, or electric—we should expect to find the specific resistance of a given wire become less the greater the length under trial; in other words, Ohm's Law would not hold true in all cases, which, however, it does.

Dividing the increase in specific resistance by the percentage given at the head of the corresponding column, it will be noticed, as already remarked, that as the alloy becomes richer in the added element, the increase of resistance caused by the addition of 1 per cent. of that element becomes progressively less; in other words, the curves as seen in Fig. 2 are steepest near their origin.

Selecting the middle column of figures and dividing it by 4, we get the increase of resistance produced by the addition of 1 per cent. of the element in an alloy containing about 4 per cent. of the added element. This is shown in the next table, and side by side is shown the specific heat and the atomic weight of the elements named in the first column.

TABLE VIII.

Iron alloyed with	Specific resistance of 1 per cent.	Specific heat.	Atomic weight.
Tungsten	1·1	0·035	184
Cobalt...	2·2	·107	59
Nickel...	2·5	·109	59
Chromium	3·0	·1 (?)	52
Manganese	5·2	·122	55
Silicon	10·3	·183	28
Aluminium...	11·1	·212	27

It will be seen, as pointed out by one of us in a recent paper at the Royal Society,[1] the increase in specific resistance follows the same order as the increase in specific heats of the various elements, with the possible exception of chromium, the specific heat of which element is doubtful, and the exact specific resistance produced by that alloy is also a little uncertain. With the same exception the atomic weight appears to decrease as the resistance of the alloy

[1] *On the Increase of Electrical Resistivity caused by Alloying Iron with various Elements and the Specific Heat of those Elements*, by W. F. Barrett, F.R.S., read February 6th, 1902 (*Proc. Roy. Soc.*, 1902, vol. 69, p. 480).

increases. This of course follows from Dulong and Petit's law, whereby the specific heat of most elements (in general those whose atomic weight is above 30) is inversely as their molecular weights. The remarkable correspondence shown in Table VIII. is, we think, more than a chance coincidence. If it should prove to be a real physical relationship, it may afford some light on the obscure question of what determines the remarkable increase in resistance when a comparatively good conductor, like aluminium, is alloyed with iron.

Some additional confirmation of this relationship is afforded by the position of *cobalt* and *carbon*. Two alloys of cobalt are given in Table III., 1209 C. and F.; these alloys contain high carbon and also some silicon, etc., but deducting the effect of these impurities on the conductivity, the cobalt curve was found to lie close to the nickel curve on the tungsten side of it. In other words, the increase in specific resistance produced by cobalt appears to be rather less than that caused by nickel but considerably more than that by tungsten. Now, the specific heat of cobalt is 0·107, and its atomic weight is 59, so that it falls into its proper place in Table VIII.

The comparative effect of carbon is extremely difficult to ascertain owing (1) to the impossibility of making alloys of iron with large percentages of carbon, and (2) the difficulty of excluding impurities such as manganese, silicon, etc., from the carbon steels. The specimens at our command did not exceed 1¼ per cent. of carbon, and were not pure alloys of carbon and iron. It is only by comparing the specific resistance of specimens with a similar amount of impurities and different amounts of carbon that an estimate of the effect of carbon can be made. From our purest commercial iron (S. C. I.) up to iron containing 0·14 per cent. of carbon the increase in specific resistance is at the rate of about two microhms for *one-tenth of 1 per cent.* of added carbon, but from 0·14 to 1·24 per cent. of carbon the rate of increase in specific resistance produced by the carbon falls to one-fourth of this, viz., *about five microhms for 1 per cent. of added carbon.* The result doubtless depends on the condition in which the carbon exists in the iron with which it is alloyed, and metallurgists have told us there is a considerable difference in this respect.

The specific heat of carbon in the form of graphite is 0·16, and in the form of diamond it is 0·113. Hence its place in Table VIII. is between nickel and manganese, and this is also its position as regards the increase of specific resistance it produces in iron for corresponding percentages.

Before any conclusive assertion can be made as to the remarkable and interesting connection which here appears to be indicated, it is necessary to wait for further evidence and also to ascertain whether any similar connection is indicated in the alloys of other metals.

(7) In all cases annealing was found to diminish the specific resistance of these alloys. In one particular composite alloy, containing 14 per cent. of nickel, 5 per cent. of manganese, and 2 per cent. of aluminium, alloyed with 78·5 per cent. of iron, the unannealed alloy had the enormous specific resistance of 89 microhms per c.c., whilst that of the same specimen annealed was 48 microhms per c.c.—a difference of 87 per cent. produced by annealing!

The effect of heat treatment on the alloys of iron containing a large percentage of manganese is, however, different from that produced on most other steels. The slow cooling of a high manganese steel hardens it, whilst rapid cooling softens it. This difference in the effect of heat-treatment probably accounts for the anomalous conductivity shown by certain specimens of manganese steels, as seen in the curves for that alloy in Fig. 2. It will be observed that the presence of carbon in any of these alloys greatly diminishes their conductivity, and also their magnetic permeability, as we shall see later on. The difference between the high and low carbon manganese steels is shown in Fig. 2; this difference is also strikingly shown in the high and low carbon nickel steels, as was seen in Table I.

A brief reference must be made to the results obtained by two or three other workers in this field. In 1885 the late Dr. J. Hopkinson, F.R.S., determined the electric resistance of a few specimens of manganese, silicon, chromium, and tungsten steels which had been subjected to different thermal treatment.[1] The general order of conductivity found by Dr. Hopkinson agrees with our results when specimens of approximately the same composition and physical state are compared. But, unfortunately, nearly

[1] *Phil. Trans.*, 1885, part ii., p. 463.

all Dr. Hopkinson's specimens had a high percentage of impurities, and his results are therefore to that extent inconclusive. In 1898 M. le Chatelier[1] determined the electric resistance of certain alloys of iron. His specimens were short bars, 20 cms. long and 1 sq. cm. in cross section, the experimental difficulties were therefore great. The total number of specimens examined by M. le Chatelier was not large, and in some the impurities were considerable. Taking the increase of resistance between the lowest and highest percentage of the added element M. le Chatelier deduced the following numbers for the increase of resistance corresponding to the addition of 1 *per cent.* of the added metal. Silicon 14 microhms, carbon 7, manganese 5, nickel 3 to 7 microhms, and for chromium, molybdenum, and tungsten he states a very small increase of resistance was produced. As M. le Chatelier arrives at these results from specimens widely differing in their limiting percentages and in their degree of purity, it is remarkable he should obtain a series of figures which are not so very different from the results we have given in Table VIII. The fact that he places molybdenum next to tungsten in the small increase in resistance it produces, is interesting as giving further support to the connection between the specific heat, or molecular weight, of the added element and the conductivity of the alloy; for the specific heat of molybdenum is stated to be 0·066 and its atomic weight is 96, so that it comes between tungsten and nickel in Table VIII. I have not had the opportunity of testing any molybdenum-iron alloys, but Mr. Hadfield informs me he hopes to make some specimens shortly and possibly some further new alloys of iron, as experiments are in progress at the Hecla Steel Works. Lead, zinc, and metals of low fusibility will not alloy with iron.

PART II.

MAGNETIC PROPERTIES OF THESE ALLOYS.

In the determination of the magnetic properties of these alloys, complete B and H cyclic curves, up to a field of 45 C.G.S. units, were made for nearly every specimen. The speci-

[1] *Comptes Rendus* of the Paris Academy, June, 1898.

mens having been made in the form of rods about a metre long and half a centimetre diameter, the yoke or ring method could not be adopted, except in a few special cases where short rods and rings of the material were made.[1] The magneto-metric method had therefore to be employed. Although this method is extremely useful for *comparative* tests, it cannot be depended upon for exact absolute determinations, more especially in rods of high permeability and where the length (as in our specimens) does not much exceed 200 diameters.

After various trials a convenient form of magnetometer was found in the magnetic system of one of Lord Kelvin's graded galvanometers, the scale of which was made to read in degrees. By sliding the magnetometer along a grooved board to a definite distance, or by the use of specially made overhead magnets of known strength, the deflections of the instrument could be adapted to suit the enormous range in permeability of the alloys to be tested.[2]

The rod under test was vertically supported inside a magnetising solenoid about 20 cms. longer than the rod itself; the position of the upper magnetic pole of the test rod in the solenoid being determined, the magnetometer was so placed (on a rigid stone pillar) as to be in a line with, and usually 45 cms. from, this pole. The effect of the external field due to the solenoid alone was neutralised by a compensating coil introduced into the main circuit, and the magnetisation of the rods due to the vertical component of the earth's force, was, in the more permeable specimens, neutralised by a single layer of wire round the solenoid, through which a very small independent current was sent with an adjustable resistance in circuit. The current in the main circuit, after traversing the usual step by step resistances, was measured by direct-reading Weston ammeters, three of which were employed; these enabled continuous

[1] For the sake of comparative tests of their electric and magnetic properties it was desirable to have all the specimens of a uniform diameter and subjected to similar mechanical and heat treatment: as several of the alloys could not be rolled or drawn much smaller than No. 5 B.W.G. (½ cm. diam.) this size was adopted throughout, though a smaller diameter would have been much better for both the electric and magnetic tests.

[2] But even the most perfectly pivoted magnetometer wears in use, and the indications become sluggish and unreliable for the measurement of small magnetic changes. This we found to be the case, and a delicate reflecting magnetometer suspended from a fibre had to be resorted to in the later experiments.

readings to be taken from 0·001 ampere up to 18 amperes. For the complete cycle 28 steps were employed, and these were repeated if the cyclic curve was found not to be perfectly symmetrical above and below the axis. Before the readings were taken, each specimen was subjected to rapid reversals of a current of gradually diminishing intensity, so that the test rod was left in a neutral condition. The determination of the value of the horizontal component of the earth's magnetic field, at the spot where the magnetometer was placed, was made with great care and checked from time to time: its value was $= 0·174$.

The length of the rods was about 200 diameters, hence a correction for the demagnetising reaction of the ends was necessary. This reaction is most felt in the downward part of the cyclic curve, especially in the more permeable specimens. The correction given by Professor Ewing for a rod of 200 diameters is shown in Figs. 3 to 8; the vertical axis o B is inclined through a small and definite angle: hence the actual value of the magnetising force H, for any given induction B, must be found by measurement from this inclined axis and not from the vertical axis oB. Later on we give the result of some careful experiments with rings and thinner rods of the same material to ascertain the validity of this correction in rods similar to those we employed.

In the next table (Table IX.) the results thus obtained with some of the alloys are given. The first column is the maker's mark for the alloy; then follows the percentage of the principal element added to the iron, the full analysis can be ascertained by referring to the corresponding alloy given in Table I.; the maximum induction in a field of 45 C.G.S. units is next given, then the permeability, $\mu = B/H$, in a field of 8; then the residual induction, or remanence, is given in terms of B, this is deduced from the point where the *sloping* line shown in Figs. 3 to 8 cuts the descending curve; then follows the coercive force (max. field $= 45$) given in terms of H; and in the last column is given the hysteresis loss, or the energy dissipated in ergs in passing the test rod through a complete cycle—this value was found by measuring the area of each curve. It will be remembered that all the specimens have been annealed.

There is no novelty in the group of *Carbon steels*, as their magnetic properties are well known; the specimen

TABLE IX.

Group.	Maker's Mark.	Percentage of Main Element alloyed with Iron.	Maximum Induction for H = 45.	Permeability μ for H = 8.	Remanence in terms of B.	Coercive force in terms of H.	Energy Dissipated per Complete Cycle.
Carbon Steels	B	0·03 C.	16800	1625	9770	1·66	10760
	L S S	·05 ,,	15720	1500	9090	1·66	11300
	611	·58 ,,	15610	1035	10370	2·56	22200
	613	1·00 ,,	14000	654	9000	6·43	32750
	614	1·25 ,,	14000	375	9040	6·43	33330
Manganese Steels ...	48	0·50 Mn.	16000	1165	10000	3·20	19650
	4147	1·00 ,,	15540	1100	11320	3·4	22150
	53	2·25 ,,	14720	1080	10460	6·0	30580
	39	4·00 ,,	9370	125	5950	16·2	39500
	34	4·75 ,,	8320	73	5420	19·6	39400
	945 A	7·00 ,,	3820	23	2230	20·0	19650
Nickel Steels	1287 D	1·92 Ni.	16000	1380	9140	2·67	15300
	1287 E	3·82 ,,	16190	1375	9320	2·76	15860
	1267 B	4·75 ,,	10500	125	6910	14·28	39800
	1287 I	11·39 ,,	8190	118	4630	17·33	32050
	1447 B	12·10 ,,	4170	—	—	22·40	21850
	1447 A	12·70 ,,	4480	—	—	22·10	24280
	1287 K	19·64 ,,	7770	90	4770	20·00	36850
	1287 L	24·50 ,,	4230	32	2790	22·50	22200
	1449	31·40 ,,	4460	357	1720	0·50	803
Tungsten Steels ...	1294 F	1·0 W.	16000	1440	10000	3·23	14150
	1294 H	3·5 ,,	15720	1280	12720	5·73	25050
	1294 I	7·5 ,,	15230	500	13280	9·02	47500
	1294 L	15·5 ,,	11090	125	9320	13·92	44000
Aluminium Steels ...	1167 D	0·75 Al.	16000	1500	10500	1·80	11000
	1167 H	2·25 ,,	16900	1700	10500	1·00	8000
	1167 I	5·50 ,,	13000	1200	4150	1·00	6500
Silicon Steels	898 E	2·5	16420	1680	4080	0·90	7900
	898 H	5·5	15980	1630	3430	0·85	6500
Copper Steels	1264 A	1·59	14600	—	10520	5·0	
	1264 B	2·5	14300	—	10410	5·4	
Chromium-Aluminium Steels ...	1178 B	1·74 Cr. 0·75 Al.	14490	1040	10350	6·0	25750
	1178 D	1·5 Cr. 2·25 Al.	13800	1180	9680	3·52	17550
	1178 E	1·5 Cr. 4·5 Al.	13150	1060	8560	1·77	13420
	1179 B	3·5 Cr. 1·0 Al.	13540	466	9550	8·0	34700
Chromium-Nickel Steels	1286 A	0·75 Cr. 2·75 Ni.	16480	1210	7730	3·0	
	1286 C	1·75 Cr. 2·5 Ni.	15150	485	11110	7·9	
	1210 D	4·5 Cr. 2·5 Ni.	13650	—	9800	13·1	
Manganese-Nickel Steel	1254 C	3·75 Mn. 4·0 Ni.	6410	121	3770	19·6	
Silicon-Nickel Steels ...	1103 A	2·0 Si. 3·25 Ni.	15750	1085	6780	2·0	
	1103 C	3·25 Si. 3·5 Ni.	15480	1240	7050	1·9	
Tungsten-Cr. Steel ...	1189 B	2·0 W. ·75 Cr.	15950	1125	12150	5·3	
Tungsten-Mn.	687	3·25 W.	15350	815	[illegible]	[illegible]	

marked B is the best Lowmoor iron, but is not as permeable as S.C.I. It will be seen from Table IX., and also from Fig. 9, that as the percentage of carbon increases, the permeability (for a field of 8) decreases regularly, and the coercive force and the hysteresis loss increases. Here, as was noticed in the electric conductivity of the specimens, small quantities of manganese impurity seriously affect their magnetic permeability.

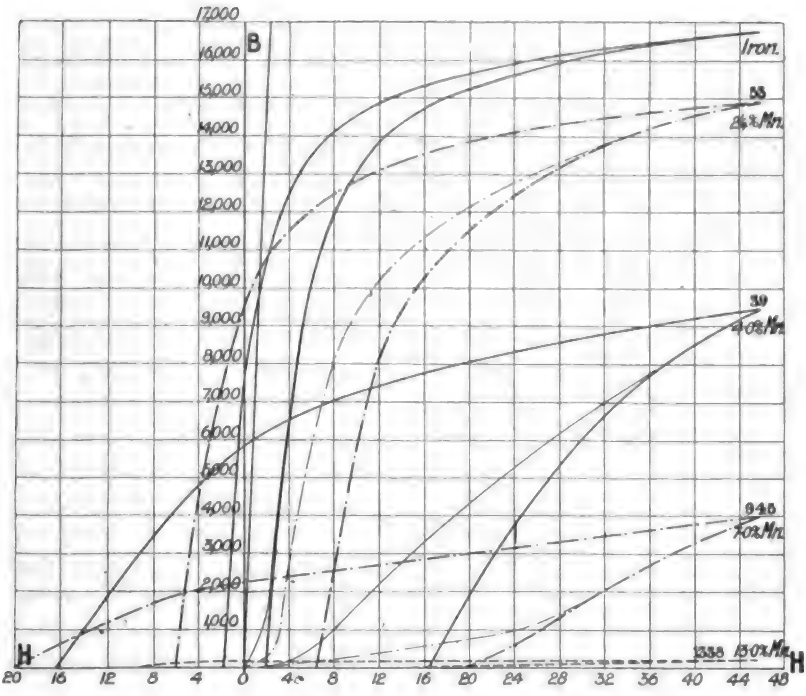


Fig. 3.—Manganese Steels.

Six of the fifteen *Manganese steels* we have examined are given in Table I.; five others, containing higher percentages of manganese, are included in Table XI., among the practically non-magnetic alloys. The cyclic curves of a few manganese steels are shown in Fig. 3.[1] A sudden drop in the permeability, and corresponding increase of the coercive force, will be noticed when the quantity of man-

[1] In all these curves the thin up-going line is that obtained from the first magnetisation of the specimen, and represents the permeability; the upper half of the cyclic curve is shown by the thicker lines.

ganese present in the alloy rises from 2½ to 4 per cent. The difference in the cyclic curve for specimens containing these two amounts of manganese is very striking. When the quantity of manganese present rises to 7 or 8 per cent., further additions of manganese have a much less effect on the magnetic properties of the alloy, which becomes practically non-magnetic when the quantity of manganese rises to 13 per cent. It is interesting to note that the electric conductivity of these manganese steels decreases rapidly up to about 7 per cent., and then falls very slowly.

A remarkable feature in the magnetic properties of manganese steels is the part played by the presence of carbon in the alloy. In *low* manganese steels, *i.e.*, when the manganese present does not exceed 3 or 4 per cent., high carbon *injuriously* affects the magnetic properties of the alloy; but in *high* manganese steels, *i.e.*, when the quantity of manganese in the alloy is 10 per cent. or over, increasing the carbon *improves* the magnetic properties of the alloy. The *hardness* of the manganese steels, as tested by the file, precisely agrees with their relative magnetic conditions. In two manganese steels with about 3·5 per cent. of manganese, but with different amounts of carbon, the one with the highest carbon was the hardest to the file, and was much worse magnetically, the induction at 45 C.G.S. being nearly three times greater with the lower carbon, and the coercive force less. But when 10 to 11 per cent. of manganese was present, the reverse was the case; the one with the highest carbon was the softer to the file, and much better magnetically. Even though this latter contained in addition upwards of 1 per cent. more manganese (*i.e.*, 11·5 per cent. against 10·1 per cent.), the induction was much higher (1,100 against 600) and the coercive force less. In a specimen containing only 0·15 of carbon and 15 per cent. of manganese, no trace of magnetic susceptibility was found in a field of 45, but when the percentage of carbon was increased ten times, *i.e.*, to 1·5 per cent., the percentage of manganese remaining the same, magnetic susceptibility was restored to a certain extent. Even an 18½ per cent. manganese steel with 1½ per cent. of carbon showed distinct magnetic susceptibility. It would have been interesting to try the effect of still further increasing the manganese, and also to ascertain whether

a very low temperature would increase the magnetic susceptibilities of these steels.

The condition in which the carbon exists in these steels (which is not shown by the chemical analysis) is a very important factor and needs further investigation. It should also be borne in mind that when suddenly quenched from a bright-red heat a low manganese steel behaves like a carbon steel and is hardened, but a high manganese steel so

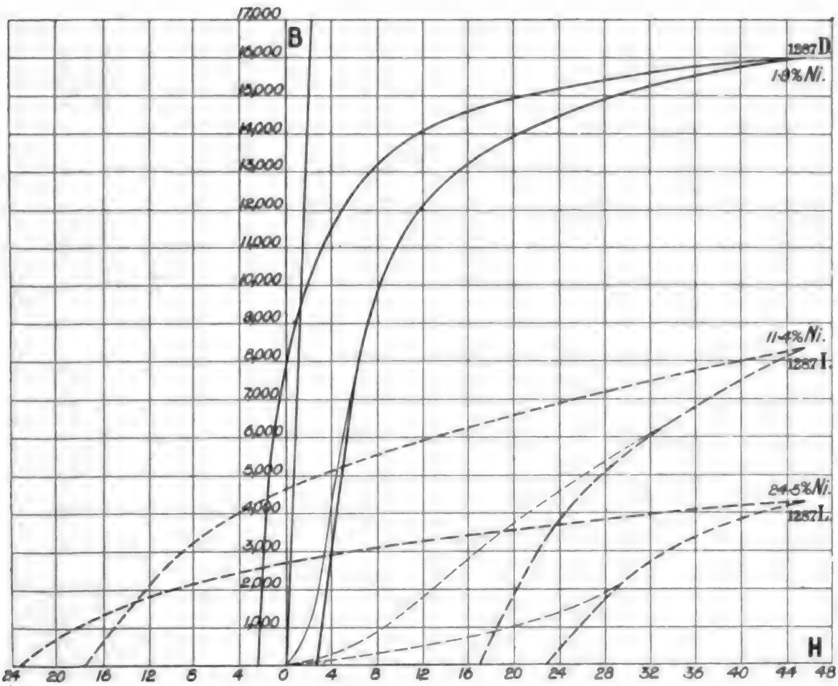


FIG. 4.—Nickel Steels.

treated is not hardened, but rendered tougher and less hard; slow cooling, in fact, hardens the high manganese steels. A 13 per cent. manganese steel is so hard that it cannot be machined, and is hardly touched by a file.

In the fine collection of *Nickel steels*, or rather nickel-iron alloys, which were tested, some points of great interest were discovered. It will be seen from Fig. 4 that a low nickel-iron alloy such as 1287 D or E is nearly as good magnetically as our specimen of Lowmoor iron, but that

the permeability rapidly decreases with increase of nickel until about 20 per cent. is reached, when a further increase in the quantity of nickel increases the permeability. This is shown by the curves in Fig. 7. In fact for very low magnetising forces the specimen 1449, when annealed, is more permeable than the best iron. The curve of permeability exactly accords with tests on the mechanical properties of these nickel alloys. Mr. Hadfield has shown

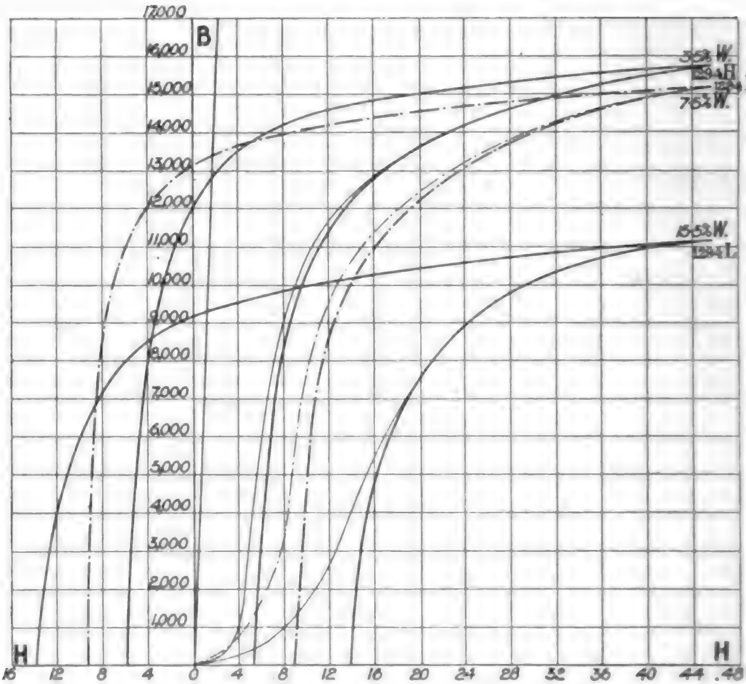


FIG. 5.—Tungsten Steels.

that nickel up to 8 or 10 per cent. increases the hardness and tensile strength of iron, but over 20 per cent. of nickel decreases it. Mechanical and magnetic softness go together here as elsewhere.

Some of the alloys of *Tungsten* are shown in Fig. 5. The very high remanence and coercive force, as well as the high value of the induction B in a 7½ per cent. tungsten steel, show that permanent magnets should be made of a steel containing from 5 to 7 per cent. of tungsten. It must be remembered that these alloys are well annealed, so that

the remanence, coercive force, and hysteresis loss would be very much greater in the hardened condition.

Chromium added to iron increases its magnetic hardness, the coercive force being considerably increased and the

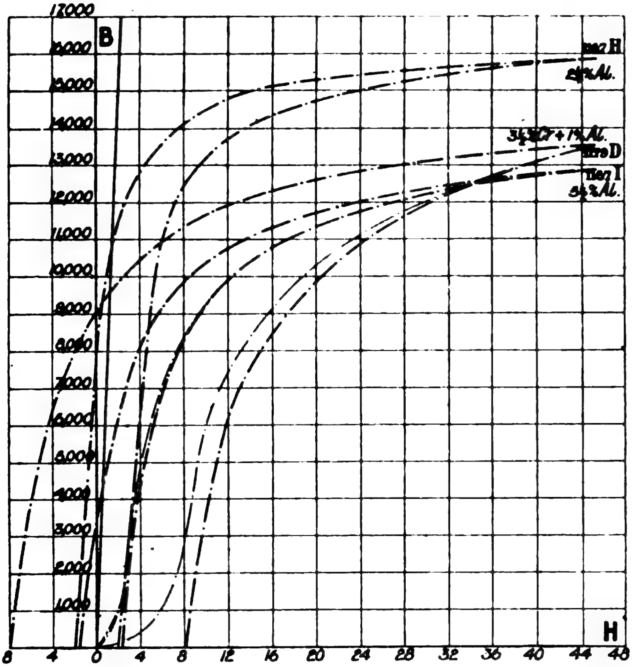


FIG. 6.—Aluminium-Iron Alloys.

permeability diminished. Copper alloyed with iron has a much less injurious effect magnetically than chromium or manganese.

The effect produced by alloying iron with *Silicon* or *Aluminium* will be dealt with more fully directly; these elements have a most remarkable softening influence on

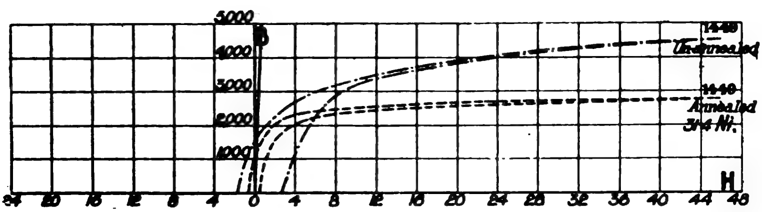


FIG. 7.—High Nickel Steel.

iron, and hence, when present up to a certain percentage, they improve the magnetic properties of the alloy. Fig. 6 shows the cyclic curves of aluminium-iron alloys; the 2¼ per cent. aluminium is better even than our standard iron.[1]

In Fig. 9 is shown the permeability of the alloys in Class I., in a field of H = 8 C.G.S. units.

Composite Alloys of Iron.

A composite alloy of Chromium and Aluminium is worse than iron or mild steel, but better than a chromium steel. The series 1178, Table IX., p. 698, has about the same amount

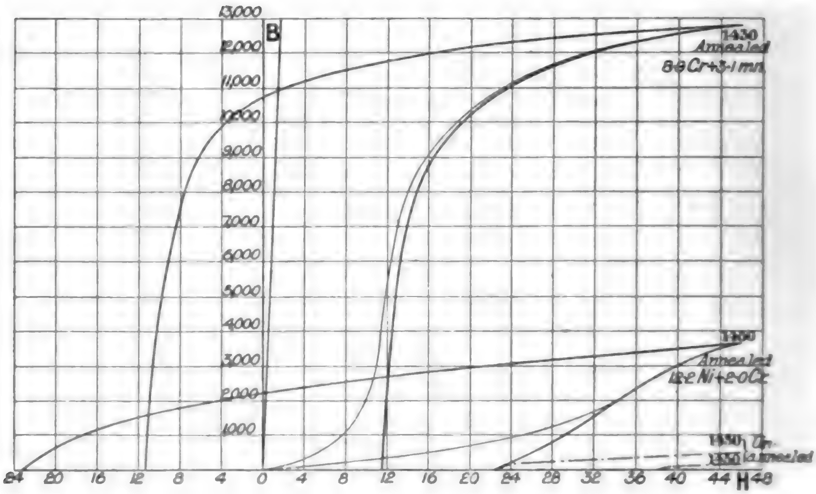


FIG. 8.—Effect of Annealing.

of chromium but varying percentages of aluminium, and it will be seen that as the aluminium increases, the steel improves magnetically. The same is true of composite alloys containing silicon, which element behaves magnetically like (but less vigorously than) aluminium. If we now take a series of steels such as 1286, containing the same amount of nickel, and add increasing quantities of chromium, the steel becomes harder and is made worse and worse magnetically, as we should expect from series 1178.

A tungsten steel with a little chromium added has its maximum induction in a field of 45 remaining much the

[1] This curve is not quite correctly reproduced in Fig. 6; the max. induction should be higher. The correct curve is given in Fig. 14.

same. But if instead of chromium we add $2\frac{1}{4}$ per cent. manganese to a tungsten steel it is made worse magnetically, the permeability being greatly reduced, and when the manganese is increased the alloy becomes non-magnetic.

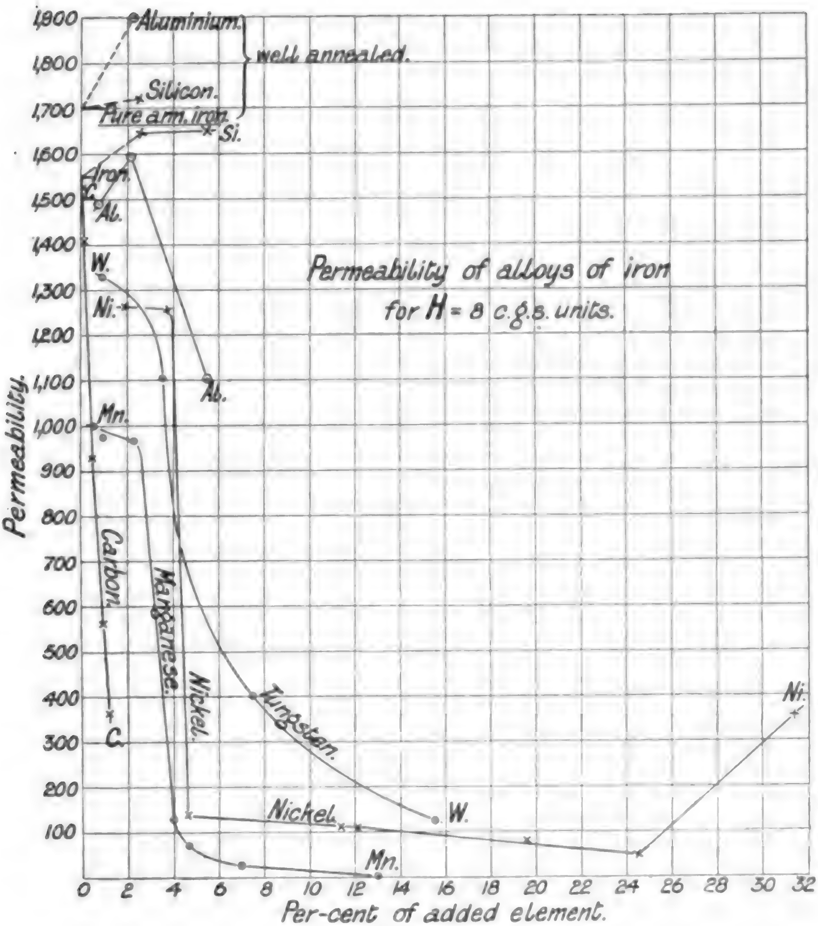


FIG. 9.

Effect of Annealing.

The effect of annealing is remarkably shown in 1430, a chromium-manganese steel with high carbon; when annealed the specimen is strongly magnetic, an induction of some 13,000 being produced in a field of 45, but when unannealed the alloy is practically non-magnetic (Fig. 8).

The same thing is true of a 12 per cent. nickel steel (1450) to which 2 per cent. of chromium is added, though its magnetic properties are much poorer than 1430 in the annealed state. Table X. exhibits the effect of annealing on the magnetic susceptibilities of some alloys; the intensity of magnetisation I and not the induction B is given.

TABLE X.

EFFECT OF ANNEALING.

Maker's Mark.		Principal Constituents.	I for field of 45.
1447 A.	Ann.	Fe. 86·1; Ni. 12·7	370
„	Un.	„ „	16
1447 B.	Ann.	Fe. 86·4; Ni. 12·1	345
„	Un.	„ „	8
1450 A.	Ann.	Fe. 85·1; Ni. 12·2; Cr. 2·0 ...	295
„	Un.	„ „ „ ...	16
1287 K.	Ann.	Fe. 79·0; Ni. 19·6	644
„	Un.	„ „	473
1430 A.[1]	Ann.	Fe. 86·7; Cr. 8·9; Mn. 3·1 ...	1046
„	Un.	„ „ „ ...	37
1411.	Ann.	Fe. 77·3; Ni. 14·1; Mn. 5·3; Al. 2·3	65
„	Un.	„ „ „ „	100
1449.	Ann.	Fe. 67·0; Ni. 31·4	195
„	Un.	„ „	346

Both the alloys 1411 and 1449 have a higher susceptibility in the unannealed than the annealed condition in a field of 45. The composite alloy 1411 is the one that exhibits the enormous increase in electric resistivity when unannealed compared with its annealed state (see p. 694).

PART III.[2]

NON-MAGNETIC ALLOYS OF IRON.

We now come to a series of alloys of iron which are practically non-magnetic. Many years ago, one of us published the result of a lengthy research on the physical properties of Hadfield's 13 per cent. manganese steel, together with an investigation of the magnetic properties of

[1] This specimen has 1·3 of Carbon.

[2] Somewhat fuller details of this and the next part will be found in a paper by the authors published in the *Transactions Royal Dublin Society* for 1902, vol. viii., part i.

a number of other alloys of manganese with steel.[1] In the first part of Table XI. is given the intensity of magnetisation, I, of a series of high manganese steels in a field of 320 C.G.S. units. A delicate reflecting magnetometer was used, and for the sake of comparison the last column shows the susceptibility in the form of percentage, iron in a field of 45 being taken as 100. The intensity of magnetisation I of iron in this field was found to be 1360. Except where the letters *Un* (signifying unannealed, *i.e.*, as rolled, not specially hardened) are attached, the specimens were all annealed. The susceptibility would of course have been very much less in all these specimens if they were hardened, or taken in a field of 45 like the iron.

TABLE XI.

NON-MAGNETIC AND NEARLY NON-MAGNETIC STEELS.

Mark.	Magnetising Force = 320 C.G.S. Units.	Intensity of Magnetisation I.	Magnetic Susceptibility Compared with Pure Iron taken as 100.
1388	Fe. 86·74 ; C. 0·26 ; Mn. 13·0 ...	65	0·7
1010 Ann.	Fe. 85·77 ; C. 1·23 ; Mn. 13·0 ...	123	1·2
" Un.	" " " ...	0	0
1379 D	Fe. 84·64 ; C. 0·15 ; Mn. 15·2 ...	0	0
30	Fe. 83·25 ; C. 1·5 ; Mn. 15·25 ...	82	0·8
598	Fe. 80·96 ; C. 1·54 ; Mn. 18·5 ...	49	0·5
1424	Fe. 76·58 ; C. 0·83 ; Mn. 5·9 ; Ni. 14·44 ; Cu. 2·25	20	0·2
1109 Ann.	Fe. 80·16 ; C. 0·8 ; Mn. 5·04 ; Ni. 14·55	3	0·03
" Un.	" " " "	0	0
1414 A Ann.	Fe. 75·36 ; C. 0·6 ; Mn. 5·04 ; Ni. 19	16	0·15
" Un.	" " " "	3	0·03
1414 B Ann.	Fe. 69·36 ; C. 0·6 ; Mn. 5·04 ; Ni. 25	7	0·07
" Un.	" " " "	5	0·05
1339	Fe. 88·22 ; C. 1·21 ; Mn. 8 ; Ni. 2.57	7	0·07
1313	Fe. 79·35 ; C. 1·4 ; Mn. 10·25 ; Ni. 9	49	0·5
1343 A	Fe. 84·71 ; C. 1.34 ; Mn. 11·1 : W. 2·85	30	0·3
" B	Fe. 86·61 ; C. 1·08 ; Mn. 10·2 ; W. 2·11	5	0·05
620	Fe. 78·12 ; C. 0·88 ; Mn. 17·5 ; Cr. 3·5	46	0·4

[1] See various papers by Professor Barrett published in the *Proceedings of the Royal Dublin Society* for 1886, 1888, 1890, etc.; also Report of the British Association, 1887, published in full in the *Electrician*, Nov. 4, 1887. His determinations of the high electric resistivity and other physical properties of these manganese steels have been confirmed by Fleming and others who have subsequently investigated this subject.

It will be seen from this table what a remarkable magnetic change is produced by the addition of a comparatively small quantity of another element to certain alloys of iron. Thus, high nickel steels are fairly magnetic, but add 5 per cent. of manganese and they become non-magnetic; albeit a 5 or even 8 per cent. manganese steel is magnetic. Add only 2½ per cent. of nickel to the latter and the alloy becomes non-magnetic, yet by itself a 2½ nickel iron is almost as magnetic as pure iron. These and other magnetic changes, such as the slight increase in magnetic susceptibility produced by the addition of copper, are, no doubt, largely due to the increased hardness or softness of the alloy thereby produced; mechanical and magnetic hardness going hand-in-hand. Hence the importance of the prior heat treatment in the susceptibility of the magnetic metals, as was so strikingly shown by Dr. Hopkinson in his experiments on the magnetic and non-magnetic states of certain high nickel steels.

Non-magnetic steels, if of good mechanical qualities and not too costly, may be found very useful; hitherto the extreme hardness of the non-magnetic manganese-steel has prevented its general use, but the alloy 1313 and several of the others on Table XI. are not very hard, and can be easily machined. Non-magnetic steel ships would be a great advantage in navigation, and these can now be made if the cost were not prohibitive.

PART IV.

ALLOYS OF IRON MORE MAGNETIC THAN THE PUREST COMMERCIAL IRON.

In conclusion, we have briefly to describe the lengthy series of experiments we have made in connection with the magnetic properties of silicon iron and of aluminium iron. Table XI. shows that these two alloys are highly permeable, and have very low hysteresis with high induction. In our memoir read before the Royal Dublin Society three years ago we showed that an alloy of 2½ per cent. of silicon or of aluminium with iron gave the most remarkable results magnetically, exceeding that of the best and purest Swedish charcoal iron we could obtain.[1] The practical as well as

[1] *Trans. Royal Dublin Society*, vol. vii., part iv., pp. 116–122; also vol. viii., part i.

theoretic importance of this discovery made it desirable to test our results in various ways, and this has been done. The long rods used in Table IX. were only 200 diameters in length, and were merely rolled so that their cross-section was not uniform. The silicon iron and aluminium iron and Swedish charcoal iron rods were therefore turned down in a lathe until they were made 255 to 260 diameters in length. Each was then heated to redness in a gas flame and allowed to cool in an E. and W. position, the heat treatment of each rod being exactly similar, though in all three the annealing might no doubt have been improved and thus their permeability somewhat increased. These were tested in the magnetising solenoid previously used, and with a delicate reflecting magnetometer placed at 70 cms. distance from the upper pole of the rod. By removal and reversals of the rods the equality of deflection in the same direction showed that they were magnetised solely by the vertical force of the earth's field,[1] the deflection produced by this field (= 0·46 unit) being very large with the aluminium iron 1167 H, less with the silicon iron 898 E, and least with the Swedish charcoal iron S.C.I. In a field of 2 units the extraordinary induction B of 12,000 was produced in the 2¼ per cent. aluminium iron 1167. Table XII. below gives the induction and

TABLE XII.

PERMEABILITY OF SILICON-IRON (898 E) AND ALUMINIUM IRON (1167 H) ALLOYS COMPARED WITH BEST ANNEALED SWEDISH CHARCOAL IRON (S.C.I.); RODS, LENGTH = 260 DIAMETERS.

H.	S. C. I.		898 E.		1,167 H.	
	B.	μ	B.	μ	B.	μ
2	7,400	3,700	10,200	5,100	12,000	6,000
4	11,150	2,790	12,300	3,075	13,800	3,450
6	12,600	2,100	13,400	2,233	14,500	2,416
8	13,600	1,700	13,800	1,725	14,900	1,862
10	14,300	1,430	14,200	1,420	15,200	1,520

[1] Owing to the length (104 cms.) and thinness of these rods, the iron (S.C.I.) could not be magnetically reversed without slight tapping, but the aluminium iron did not require this. See page 722.

permeability in fields up to 10 units of these three bodies. The value of the earth's field at the place and time of experiment was again carefully determined.

These results are shown in the permeability curves given in Fig. 10.[1] The correction for the demagnetising reaction of the ends is not shown on the diagram, but is allowed for in Table XII.

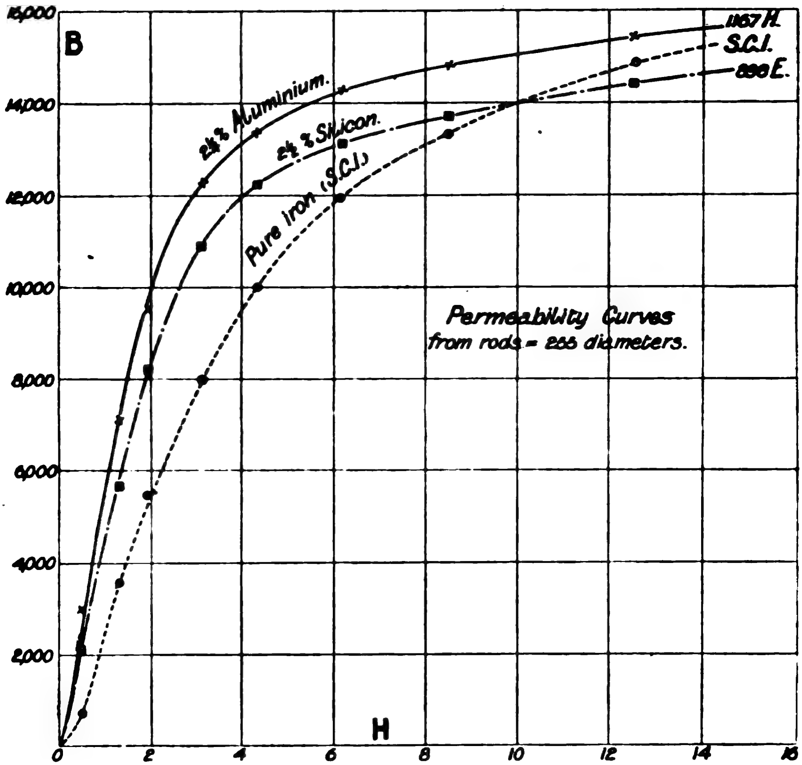


Fig. 10.

These results were checked by having some specimens made in the form of short rods, and testing them in a yoke by means of Professor Ewing's Permeability Bridge. The results are given in Table XIII.; differences in annealing account for some of the slight differences observed, but the

[1] In Fig. 10 the curve for S.C.I. up to a field of 6 is a little low, as found by a subsequent experiment after re-annealing the rod; the numbers in Table XII. are taken from this last determination: the rods were also tested ballistically by a coil in their centre.

relative values are much the same. In Fig. 11 the permeability is shown plotted against the magnetising force H.

In Professor Ewing's Permeability Bridge the short rod under test is balanced against a standard rod by varying the strength of the magnetic field round it until the induction is the same in both rods; the equality being indicated by a

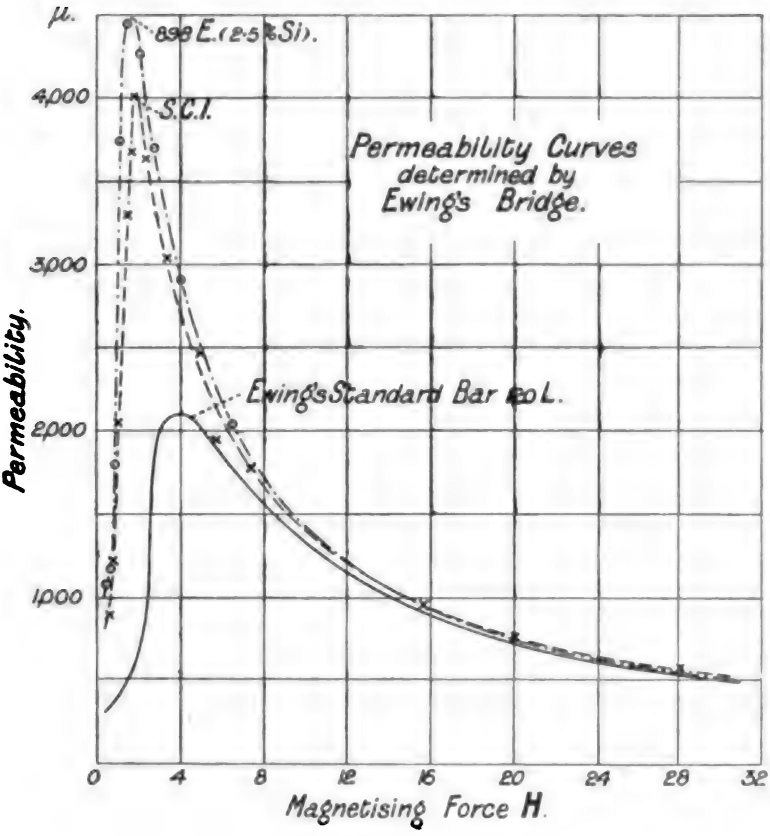


FIG. 11.—Permeability of Swedish Charcoal Iron and Silicon Iron.

magnetic needle placed between two conducting iron horns leading from the yoke. The up-going B and H curve can thus be obtained, but not the cyclic curve, and therefore not the hysteresis loss. It will be seen from Fig. 11 that our specimen of standard iron S.C.I. considerably exceeds in permeability the standard iron 120 L supplied with the instrument. (See also Fig. 14, p. 718.)

TABLE XIII.

COMPARISON OF MAGNETIC INDUCTION (B) AND PERMEABILITY (μ) IN PURE IRON AND 2½ PER CENT. SILICON IRON ALLOY IN DIFFERENT FIELDS, AS DETERMINED BY EWING'S BRIDGE.

H.	S. C. I.		898 E.	
	B.	μ	B.	μ
2·0	7,120	3,560	8,640	4,320
3·0	9,520	3,173	10,400	3,466
4·0	10,800	2,680	11,680	2,920
5·0	11,680	2,336	12,500	2,500
6·0	12,440	2,073	13,040	2,173
8·0	13,360	1,670	13,760	1,720
10·0	14,000	1,400	14,240	1,424

Another set of experiments was made with *rings*, the ballistic method being employed; an excellent Crompton bifilar ballistic galvanometer being used for the purpose. The deflections were calibrated and their value found, for a given induction, by an earth inductor, and also by a specially wound standardising coil. Unfortunately a ring of the aluminium-iron alloy has not yet been tested, but from annealed forgings of S. C. I. and the silicon iron 898 E rings were very accurately turned; the cross-section (like that of a curtain ring) was 9·02 cms. diameter, the cross-sectional area being 0·73 and 0·76 sq. cms. respectively. The density of these rings was found to be, for S. C. I. 7·84, and for 898 E, 7·66. After a final and careful annealing the rings were wound with 600 turns in the primary and 200 turns in the secondary coil.

The result of these experiments has been plotted in the form of cyclic curves which closely resemble the corresponding curves for the rods given in Fig. 12. Analysis showed that the casting from which the 898 E ring was made was slightly richer in silicon. Here is the percentage composition of the principal constituents of the specimens tested :—

Mark.	Iron.	Carbon.	Silicon.
S. C. I.	99·9	0·03	0·07
898 E rod	97·3	·2	2·5
898 E ring	96·9	·2	2·87

As the S. C. I. was the same composition in ring and rod, an opportunity was afforded of comparing the results

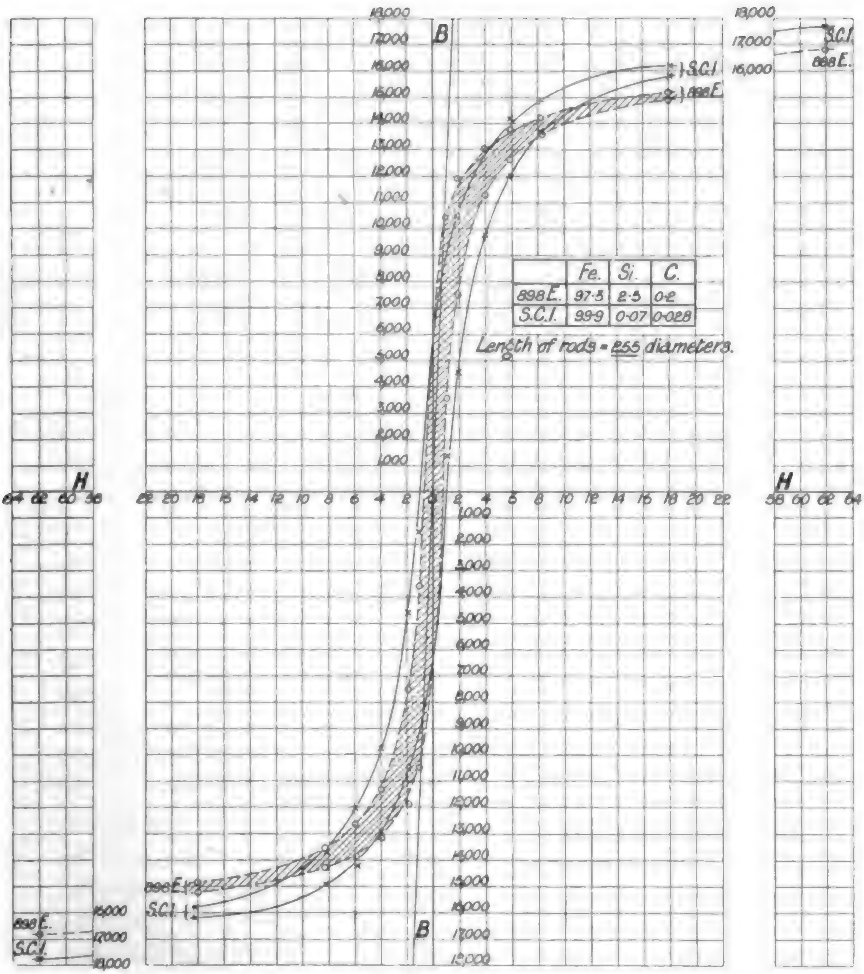


FIG. 12.—Cyclic Curves of Swedish Charcoal Iron compared with Silicon Iron, both in the form of long slender rods.

obtained by the two methods, and testing the accuracy of the correction for endlessness in the case of the rod. The result is as follows, the correction being shown by the sloping vertical axis in Fig. 12.

TABLE XIV.

Determination of the Magnetic Induction (B) in Pure Iron by the Ballistic Method (*ring*), compared with the Magneto-metric Method (*rod*, length = 255 diameters) corrected for Reaction of Ends.

S. C. I.

H.		B. Ring.	B. Rod.	Difference.
Up Curve ...	4	12,250	11,150	1,100
	6	13,600	12,900	700
	8	14,300	13,800	500
	10	14,700	14,500	200
	12	15,200	15,200	0
	14	15,400	15,400	"
	16	15,700	15,700	"
	18	15,800	15,800	"
	60	17,600	17,600	"
Down Curve	18	16,200	16,200	"
	16	16,100	16,100	"
	14	16,000	16,000	"
	12	15,900	15,900	"
	10	15,700	15,700	"
	8	15,500	15,200	300
	6	15,250	14,650	600
	4	14,800	13,600	1,200

The agreement is surprisingly good in fields of ten and over; in lower fields the difference is probably due to the fact that the rings were rather better annealed (as indeed was the case), and this shows itself in the lower fields.

A series of cyclic curves for different points of maximum induction were obtained from the rings, and are shown in Fig. 13. From these curves the data given in Table XV. are deduced. It will be seen that in all cases, with a given maximum induction, the silicon iron is better magnetically, and doubtless could be still further improved by careful attention to annealing and by reducing the small percentage of carbon and manganese it contains, and also possibly by slightly altering the percentage of silicon.

The alloy itself is a soft and beautiful one, easily worked and takes a good polish, but rusts more easily than pure iron. Its commercial value in the construction of transformers and other machines where a high magnetic permeability is necessary, is obvious; and it so happens that transformers are now worked at the maximum induction which is best suited to silicon iron.

TABLE XV.

ANNEALED SWEDISH CHARCOAL IRON (S. C. I.).

Max. Induction in C. G. S.	Remanence.	Coercive Force.	Hysteresis Ergs per c.c.	Hysteretic Constant η.
17,700	10,800	1·10	8,754	·001397
11,970	9,090	0·95	3,572	·001067
9,907	7,850	0·91	2,732	·001104
4,944	3,975	0·72	943	·001158

ANNEALED SILICON IRON (898 E).

Max. Induction in C. G. S.	Remanence.	Coercive Force.	Hysteresis Ergs per c.c.	Hysteretic Constant η.
17,500	8,000	0·80	6,730	·001094
11,260	7,375	0·78	2,710	·000892
9,440	6,600	0·70	2,000	·000873
5,079	3,850	0·54	741	·000872

It only remains to give the still more remarkable results obtained with the 2¼ per cent. aluminium iron 1167 H. The rod was turned down to give a length = 260 diameters, and its cyclic curve compared with that of a similar rod of S. C. I., both being annealed alike. The result is shown in Fig. 14, the comparative experiments being made under precisely similar conditions. It will be seen that not only is the permeability greater, but also the maximum induction in all fields up to about 60 units is greater in the case of this aluminium iron than in any magnetic body, including the

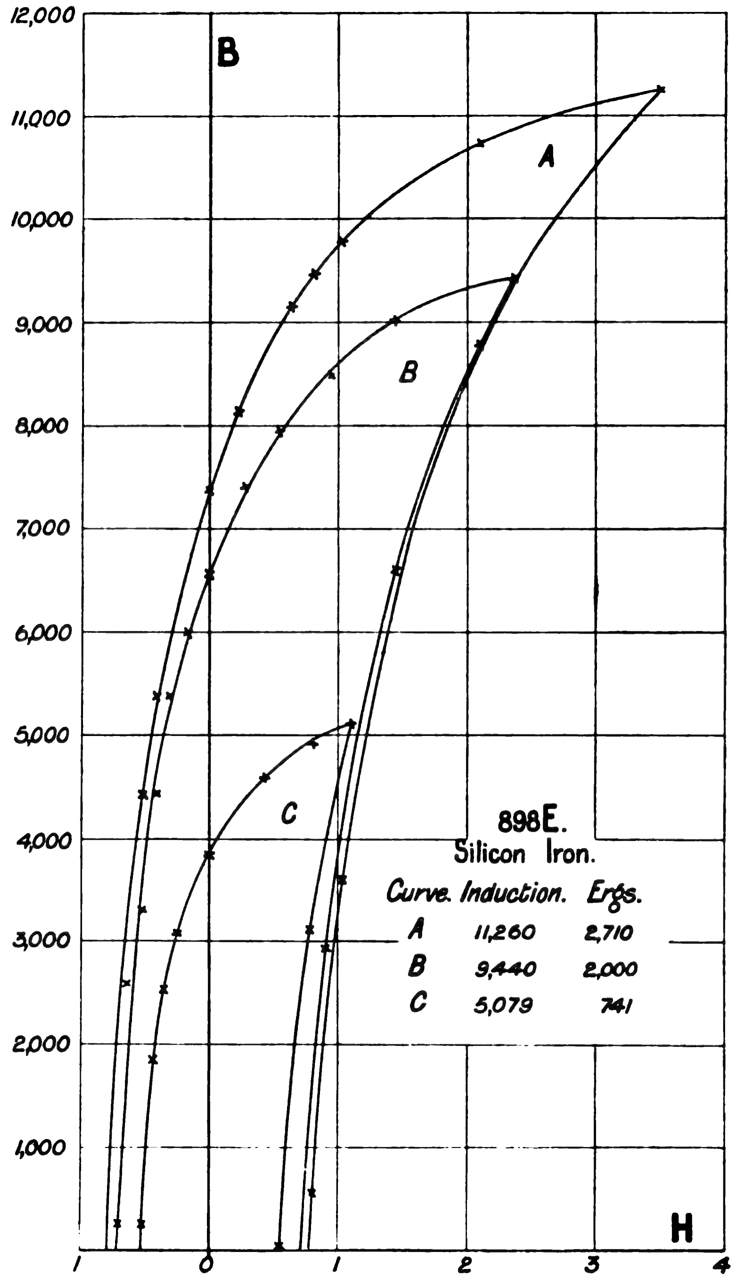

12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
B
A
B
C
H
1
0
1
2
3
4
898E.
Silicon Iron.
Curve. Induction. Ergs.
A 11,260 2,710
B 9,440 2,000
C 5,079 741

FIG. 13.

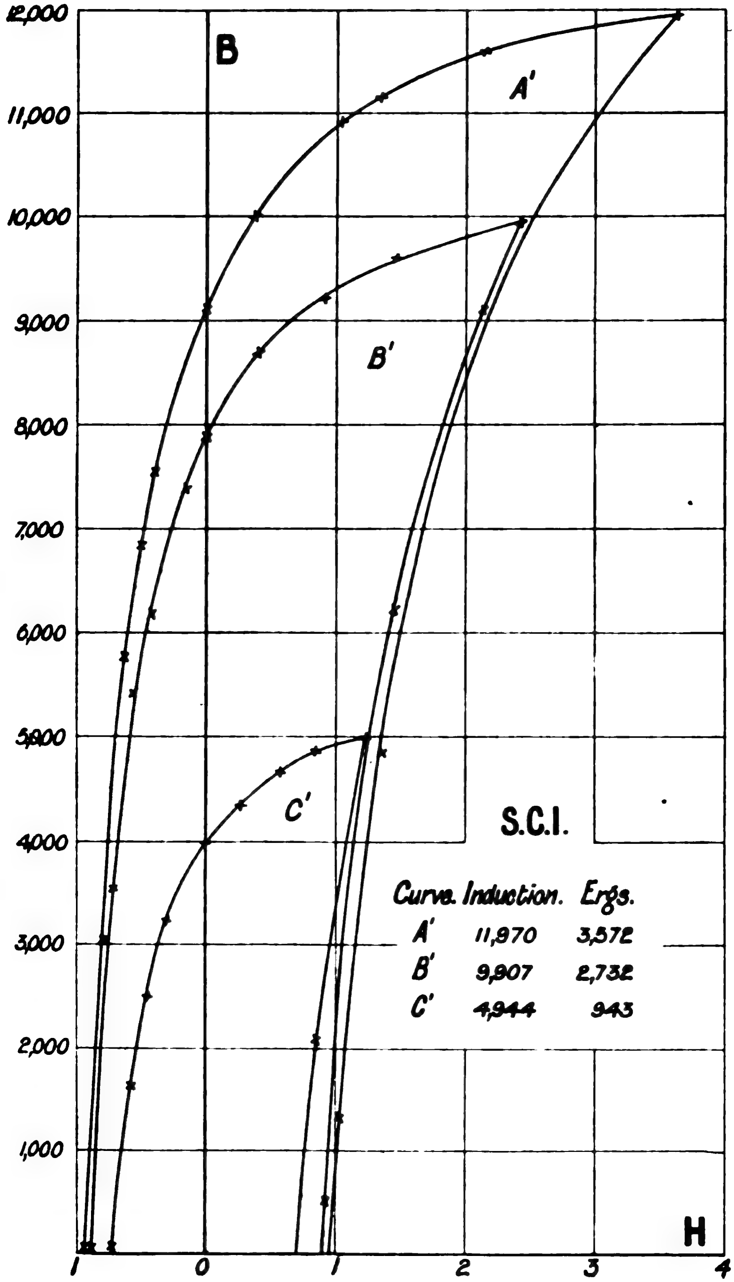

B
A'
B'
C'
S.C.I.
Curve. Induction. Ergs.
A' 11,970 3,572
B' 9,907 2,732
C' 4,944 943
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4000
3,000
2,000
1,000
H
1
0
1
2
3
4

FIG 13.

purest iron, we have yet tried. From a theoretic point of view it is a very extraordinary fact that replacing the quantity of pure iron in a body by 2¼ per cent. of a non-magnetic body should so wonderfully increase its magnetic

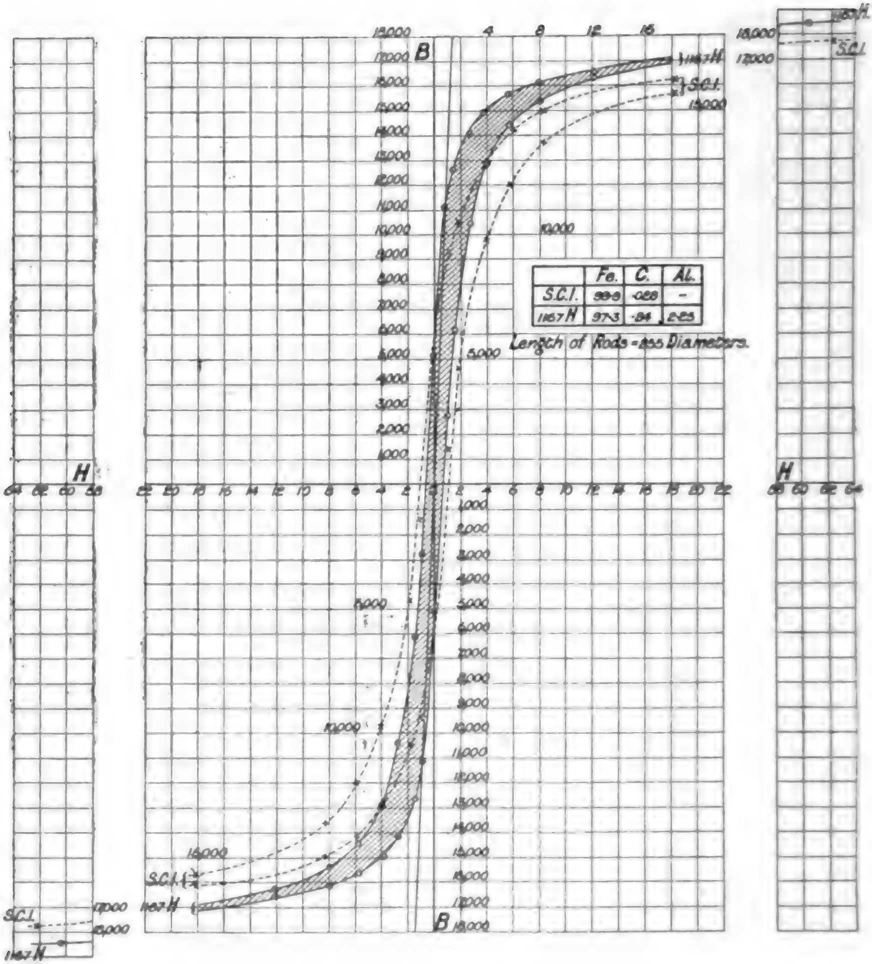


FIG. 14.—Cyclic Curve of Swedish Charcoal Iron compared with Aluminium Iron, both in the form of long slender rods.

qualities. The explanation is possibly to be found in the strong chemical affinities of both aluminium and silicon for oxygen and the halogens. It may be that the addition of a small quantity of these elements by combining with and thus removing any oxygen or oxide of iron in the molten

metal leaves the granules of iron purer and more uniform in texture than they otherwise would be. But the question is one demanding further investigation.

In the next Tables XVI. and XVII. is given a summary of the hysteresis losses of the specimens of silicon and aluminium iron we have tested, compared with ordinary good iron and the best Swedish charcoal iron, at the maximum induction of 9,000 and 5,000 respectively.

TABLE XVI.

HYSTERESIS LOSSES FOR MAX. INDUCTION = 9,000 AND FREQUENCY = 100 OF RODS OF SILICON IRON (898) AND ALUMINIUM IRON (1167), COMPARED WITH ORDINARY AND PURE SOFT IRON (S.C.I.) ALL ANNEALED.

Mark.	Density.	Hysteretic Constant η	Microwatts per C.C.	Watts.	
				Per cub. inch.	Per lb.
Soft iron	7·78	·002	42,440	0·695	2·50
S.C.I.	7·84	·0011	23,340	0·382	1·35
898 E	7·66	·00073	15,490	0·254	0·92
1167 H	7·56	·00068	14,430	0·236	0·86

TABLE XVII.

HYSTERESIS LOSSES IN S. C. I. AND 898 E (IN FORM OF RINGS), COMPARED WITH GOOD SOFT IRON, FOR MAXIMUM INDUCTION **B** = 5,000 LINES PER SQ. CM., AND FREQUENCY n = 100.

Mark.	Hysteretic Constant η	Hysteresis Losses.		
		Microwatts per C.C.	Watts.	
			Per cubic inch.	Per lb.
Soft Iron	0·002	16,576	0·272	0·96
S. C. I.	0·0011	9,116	0·149	0·53
898 E	0·0008	7,457	0·123	0·44

Herr Kamps has shown, from the investigations he has lately published in *Stahl und Eisen*, that the method and duration of annealing is an even more important factor in the magnetic qualities of iron and steel than had been supposed. A magnetic body can be *over* annealed as well as under annealed; the duration of annealing depending on the composition of the particular specimen of steel. Hence it is possible that the aluminium steel alloy may be raised still higher magnetically by attention to its annealing period. Kamps gives the following data as the highest he has reached in very thin strips of selected iron, or mild steel, which had been annealed for thirty-five hours :—

Magnetising force	=	150
Maximum induction	=	17,430
Remanence	=	10,400
Coercive force	=	0·44
Hysteresis loss (ergs per c.c.) ...	=	5,770

A long annealing injured this specimen magnetically. The author unfortunately does not give the analysis of this iron.

Messrs. J. Sankey & Sons, of Bilston, have sent us a specimen of the iron they manufacture for transformers, the permeability of which, by careful attention to annealing, they have raised to an unprecedentedly high value. They inform us that the actual hysteresis loss of their transformer iron as tested by Professor Ewing is only 0·32 watts per lb. for B = 4,000 and 100 cycles per second. Using the first two letters in the words "low hysteresis," they term their product "Lohy" iron. Its ageing value is not stated, but experiments are now in progress in our laboratory at the College of Science in which this is being tested and compared with our silicon and aluminium alloys, and with Swedish charcoal iron; also, by the immersion in oil of small model transformers made of these materials, a direct measurement of the relative hysteresis loss is now being made by taking the rise of temperature during working at different values of maximum induction.

Taking the maximum induction at 4,000 and 100 cycles per second as above, our results show that the silicon and aluminium iron alloy carefully annealed are considerably

better even than the Lohy iron. The figures are as follows :—

S. C. I.	... ...	0·38 watts per lb.
898 E.	... ...	0·26 „ „
1167 H.	... ...	0·23 „ „

The last might probably be reduced even lower by further annealing. Experiments are now in progress with a ring of the aluminium-iron alloy (only recently obtained) with which the cyclic curve and hysteresis loss can be more accurately determined. The high permeability of this alloy would doubtless be still further increased by reducing the carbon it contains and by a slight alteration in the amount of aluminium present.

In conclusion, we desire to thank Mr. S. A. Edmonds, senior student in the Physics faculty of our college, for much useful assistance he has given in the experimental work in the latter part of this paper.

At the conclusion of his paper Professor BARRETT said :—

I have brought over some of the actual rods used in these determinations. These three—Swedish charcoal iron, silicon-iron, and aluminium-iron—have been turned true to the same diameter, about one-seventh of an inch, and when the length (40 inches) of these rods, or wires, is considered, you will see this is a very skilful piece of work, done by one of the best mechanicians I have ever known, an Irishman, Mr. Michael Lambert. Holding the aluminium-iron vertically, with its lower end about a foot distant from this small magnetic needle, you will see by the motion of the index, that the north-seeking end of the needle is repelled through a large angle. Now I will, without shaking it, very gently reverse the long, slender aluminium-iron rod ; instantly the magnetism of the rod is completely reversed and the north pole again repelled through the same angle, the distance apart being as before. That is to say, the vertical force of the earth's magnetism has not only magnetised the material powerfully, but so wonderfully soft, in a magnetic sense, is this alloy, that its polarity is instantly and completely reversed by turning it upside down. With a shorter or thicker rod this might be expected, but with a long, slender rod or wire like this, upwards of 260 diameters in length, the effect is certainly remarkable. Repeating the experiment with a similar rod of Swedish charcoal iron, the magnetisation, you observe, is much less and the reversal is not so complete. The rods being successively held vertically at similar distances from the needle, the tangents of the angles of deflection—produced by the magnetisation due to the earth's field—measure their comparative permeability. The scale readings (which

are proportional to these tangents) are as follows, exactly the same distance being preserved in each case:—

Swedish charcoal iron	35,	when reversed	15
Silicon-iron alloy...	60,	„ „	58
Aluminium-iron alloy	90,	„ „	90

Here is another interesting illustration of the great magnetic softness and high maximum induction of the aluminium-iron, which I happened to notice when submitting these alloys to an alternating current. When an interrupted or alternating current is sent round a magnetic metal, a sound is produced at every break or reversal of the current. This is the so-called "Page effect," and gave rise to the first telephone by Reiss. The sound is due to the molecular changes accompanying magnetisation and demagnetisation. I will now send an alternating current round this solenoid, within which I can place one of the thin iron rods, the whole being mounted on a sound-board. No sound is heard until I insert the rod of Swedish charcoal iron, then a loud humming note is heard, due to the number of alternations per second and the consequent number of reversals of magnetisation in the iron. Reducing the current strength till it is less than an ampere, the note becomes hardly audible. Keeping the current strength at this small amount and changing the rod for one of silicon-iron a louder note is heard; changing this for the aluminium-iron rod, we can all hear the astonishing increase in loudness produced by the magnetisation of this material. The current, the mass of each rod, and their annealing are all alike, so that the louder sound is due to the more powerful magnetic induction taking place in the aluminium-iron, and its softness renders the magnetic lag less. This I think is a novel way of exhibiting the relative permeability of magnetic bodies. Perhaps, by a sort of induction balance, it may afford a quick measure of permeability. With manganese steel or any of these very low magnetic bodies, you will observe that no sound is heard when they are placed in the solenoid; obviously so, for a current enormously stronger would be required to make any sound audible in these nearly non-magnetic bodies.

Lord Kelvin.

Lord KELVIN: I am sure we have all listened with extreme interest to the paper. The amount of labour which has been devoted to this exceedingly important investigation must strike every one present this evening. The results speak for themselves. The enormous increase in the permeability of iron produced by the addition of 2½ per cent. of aluminium is certainly a magnificent result, accompanied as it is by great diminution in retentiveness. No one can foresee of how much value this investigation may be, but I think all of us feel that it may be of very great value indeed in respect of the use of iron in transformers. Professor Barrett described an experiment in which the heating effect was compared in different specimens. That goes at once to the root of the matter in respect of the practical application for transformers. It was a most interesting experiment, in which we heard the much greater sound in the case of a core of aluminium iron than in the case of the

core of the very best Swedish iron. That is exceedingly important and interesting in many respects; but the fact of there being decidedly less heat in one case than in another goes more directly still to the root of the matter in respect of its value for use in transformers. I would like to ask Professor Barrett one question. While there is very much less of heating effect, does the experiment show, with the same transforming efficiency and the same amount of kilowatts or fraction of a kilowatt transformed, that there is much less heat in the case of the aluminium iron than in the case of the Swedish iron? I think one may gather from the statement he has put before us that there is; but I do not know whether Professor Barrett can give us a definite statement on that point. Lord Kelvin.

Professor BARRETT: May I answer that question at once? I may say that we have not completed as yet experiments directly measuring the heat produced. Those experiments are actually in progress in my laboratory at the present time. I find the following a very simple way of getting the result. Simply put a glass tube filled with water inside a long magnetising solenoid, with a capillary tube at the end. Then put one of the little rods inside, and send an alternating current round it for a definite period of time. The water expands, and the amount of expansion measures the heat produced in the rod. The energy that would be dissipated in the form of heat as deduced from the area of the hysteresis curve is given at the end of the paper. The figures are as follows:— Professor Barrett.

Hysteresis Loss for Max. Induction = 4000 and 100 Cycles per Second.

Swedish Charcoal Iron	0·38 watts per lb.
Lohy Iron...	0·32 ,, ,,
Silicon Iron	0·27 ,, ,,
Aluminium Iron	0·23 ,, ,,

Professor Ewing, I understand, has examined seven specimens of Lohy iron made by Messrs. Sankey & Sons, who have furnished us with the results so obtained. Very much, of course, depends upon the annealing. The above figures are the results as regards the loss of energy expressed in watts per lb., as determined by the area of the hysteresis curve, not by the actual heating, and are deduced from the Steinmetz constant obtained from a maximum induction of 9000.

Lord KELVIN: I am sure we have all been pleased by the answer. I think we may take it that there is much promise here of improvement in iron for transformers, and also for the armatures of continuous-current dynamos. It is not often that a long laboratory series of experiments leads directly to such important practical results; and I am sure we all wish to express our gratitude to Professor Barrett for having taken so much trouble in coming over from Dublin to describe his results to us. We all wish to congratulate him on having obtained such very interesting and such very important results after so much persevering labour. Lord Kelvin.

Dr. R. T. GLAZEBROOK: I should like to say that I have felt very much interested indeed, especially with the last results that the author Dr. Glazebrook.

Dr. Glazebrook. has put before us, with regard to the aluminium-iron and the silicon-iron. As I read his abstract and heard him speak, the suggestion crossed my mind as to whether it would not be worth while to institute a microscopic examination of these irons, with the view of seeing, if we can, what is the small internal change of structure that has taken place which has led to such striking and remarkable results. We know how much has been due in recent years to the microscope with regard to the effect of carbon in iron and the changes that take place in consequence of its presence; the relation between the amount of carbon and the tensile strength of the iron, and so on. I venture to think that a similar series of researches on the silicon and aluminium alloys, which Professor Barrett has brought before us, would lead to very interesting and important results, and might possibly enable us to get even further than he has done with these strikingly high values for the induction and low values for the hysteresis loss.

Capt. Creak. Captain CREAK, R.N.: I should like to ask Professor Barrett if, as he has given us an iron alloy which is non-magnetic, whether it is also workable for building ships. The difficulty we have had to face in non-magnetic alloys of iron on board ship, is that we cannot utilise them.

Mr. Campbell. Mr. A. CAMPBELL: There is one little point I should like to raise with regard to the resistivity of the special aluminium alloy. Figure 2 indicates that the resistivity of this aluminium alloy comes out very high; it seems to be about 45. It appears to me that this, in addition to its excellent magnetic qualities, makes it a very desirable substance for the construction of transformer plates. With such high resistivity we should expect very small eddy currents. Thus it would be possible to use very much thicker sheet than is necessary in the usual construction; in fact we get rid of the trouble of eddy currents to a large extent. I should be glad if Professor Barrett could assure us of that.

Mr. Mordey. Mr. W. M. MORDEY: I should like, if I may be allowed, to make a correction. I have only just noticed that in the last paragraph of the paper Professor Barrett refers to the ageing of iron. I am sure he will be glad to hear that ageing is a thing of the past. Experiments initiated by me have been going on for some eighteen months on this "lohys" iron of Messrs. Sankey without any sign of ageing. Perhaps Professor Barrett has got something better, but as far as I know this is the best obtainable commercial iron. He is quite right in saying that if ageing occurs it is necessary to re-anneal the iron to get rid of the effect; but that does not prevent ageing occurring again in the same iron. I am, therefore, very glad to be able to say that non-ageing iron is now to be got. Of course the ageing was not caused directly by the magnetic changes, it was only shown magnetically. It was due to heat causing a change of physical condition, as I was able to show in a paper read before the Royal Society in 1896.

Professor Barrett. Prof. BARRETT: I am very glad to hear that "ageing" in iron has been overcome, if Mr. Mordey's statement is confirmed by longer and wider experience. Messrs. Sankey certainly have a wonderful annealing process; but I believe they keep it a secret.

Prof. E. Wilson (*communicated*): Part IV. of the paper deals with a subject of great interest, namely, the effect upon magnetic quality of alloying iron with aluminium or silicon. The greatest use of aluminium at present is in the purification of iron. From 2 to 5 lbs. of aluminium per ton is sufficient to render the iron more fluid in the ladle and to free it from blowholes. At high temperatures aluminium decomposes nearly all metallic oxides, and its action in the purification of iron is stated to be about twenty times as powerful as that of silicon. One would expect, therefore, that the presence of aluminium in small quantities might produce a material whose magnetic quality might be improved, and that aluminium might be more powerful than silicon. Professor Wilson.

About four years ago I published the results of experiments made upon very pure iron[1] supplied by the Elswick works. It has the following composition:—Carbon, trace; silicon, trace; phosphorus, none; sulphur, ·013: manganese, 0·1, and in the following table I give a few figures to compare with the author's Tables XII.—XV.

Limits of B.	Swedish Iron (Ewing).		Elswick Iron.		Silicon Iron, 898 E.		Aluminium Iron. 1167 H.
	Ergs.	μ	Ergs.	μ	Ergs.	μ	μ
5,000	910	4,230	1,010	4,350	741	—	—
9,000	2,310	4,090	2,450	5,490	—	—	—
9,440	—	—	—	—	2,000	—	—
10,000	—	3,790	2,860	5,460	—	—	—
10,200	—	—	—	—	—	5,100	—
12,000	—	—	—	4,900	—	—	6,000

The above figures show that the Elswick iron, free from aluminium, and with a trace of silicon, can have a maximum permeability greater than the silicon iron 898 E, but inferior to the aluminium iron 1,167 H, and that high permeability is not necessarily accompanied by low dissipation of energy per cycle per cc. due to magnetic hysteresis for the same limits of B.

A matter of great importance to engineers is that of the ageing of iron. The ageing of permanent magnets is carried out artificially, and I believe that a certain firm is prepared to guarantee that a certain class of iron, after passing through their ageing process, will not exhibit a larger dissipation of energy by magnetic hysteresis for given limits of B after a considerable period of magnetic reversals, as in the cores of alternate-current transformers. It would be valuable if the authors could test their good specimens in order to see if they are

[1] See *Proceedings Royal Society*, vol. 62, p. 369.

Professor Wilson.

liable to deteriorate rapidly; it happens that the best quality at the start does not always last so well as a poorer quality.

Mr. T. W. Hogg[1] has made some interesting statements in connection with alloys of aluminium and ferro-manganese. He states that one alloy, containing Al. 3·05, Fe. 15, and the rest manganese, is as easily attracted by a magnet as iron. In another alloy, containing enough manganese and aluminium to destroy magnetism if present separately, together the substance is magnetic, though containing less iron than in the above alloy.

To test these points the British Aluminium Company kindly prepared for the present writer three rings, containing respectively:—

Al.	Fe.	Mn.
3	15	82
20	68	12
20	80	—

Each of these rings is practically non-magnetic when tested by the ballistic galvanometer method. One can be easily deceived by testing with a magnet to see if a substance is magnetic, as it is difficult to differentiate between small and large permeability.

Referring to alloys of nickel-manganese and iron, I may mention that one of Mr. Hadfield's alloys, containing Ni. 25, Mn. 5·04, C. ·8 per cent., has a specific resistance of over 88×10^{-6} ohms at atmospheric temperature.[2] This is in good agreement with the specific resistance given by the authors for the alloy 1414 B., Table II. When tested for magnetic quality, a ring having the above composition was non-magnetic when at the temperature of liquid air (— 182° C.), and again when at atmospheric temperature, nor could it be rendered magnetic by heating to 836° C.

Mr. Stoney.

Mr. GERALD STONEY (*communicated*): There are several points of great interest to a practical electrical engineer in this instructive paper. First, as regards the *non-magnetic alloys*, perhaps they may prove a substitute for brass or manganese bronze in many cases in dynamo building. No. 1313 alloy is practically non-magnetic, and its conductivity is only about one-seventh that of iron, so that I should expect that it would heat less in a magnetic field than brass or manganese bronze, which are fairly good conductors. It would be interesting to know the tensile strength and elongation of this alloy 1313, and also whether sound castings can be made and whether it can be rolled into sheets. As regards the *magnetic alloys*, the increased permeability is very important in the aluminium iron alloy if it can be easily cast or rolled, and the hysteresis does not increase with "ageing." The conductivity of this alloy being so much less than iron will reduce the eddy currents proportionally. Eddy current losses in armatures, etc., are quite as important as hysteresis losses, and with the same eddy current loss plates of double the thickness could be used, a most

[1] See *British Association Report*, 1892.
[2] See *Electrician*, November 9th, 1900.
[3] See *Transactions Royal Dublin Society*, 7, pp. 67–126, January, 1900.

important point both from mechanical reasons and as regards cost of building and stamping core plates; for the cost of construction is practically as the number of plates in a core and not as their thickness; also the insulation space will be less, which is another gain. Mr. Stoney

I heartily congratulate the author on his investigations, the importance of which to the dynamo builder is very great.

The CHAIRMAN: Before calling on Professor Barrett to reply, I think I should say that we are greatly indebted to him for the paper he has given to us, because it is full of so much detail. It is very valuable to have the results of such experiments brought before us. It is very much better than talking on general principles. Certainly Professor Barrett has given us an enormous amount of detail. I called upon Dr. Glazebrook to see if he had anything to say, because we have now established the National Physical Laboratory, and a work of the sort that Professor Barrett has been engaged on should surely fall within the province of a public laboratory instead of being carried out at the expense and the personal trouble of a man who has so many other occupations. Of course it is a pleasure to Professor Barrett to carry on the experiments; but now that we have the National Physical Laboratory I hope that Dr. Glazebrook will be able to follow the investigations further, and perhaps give us some fuller results. There is another point in connection with this paper that I should like to mention. Professor Barrett said to me that he doubted very much whether this was a class of paper which should be brought before the Institution of Electrical Engineers, and he doubted it so much that if our friend, General Webber, had not successfully drawn him, we should not have had him here to-night to read the paper; we have therefore to thank General Webber to a certain extent for Professor Barrett's very interesting paper. The Chairman.

Dr. GLAZEBROOK: Sir, may I thank you for what you have said about the National Physical Laboratory, and say that we shall be glad to give any assistance to Professor Barrett that we can in carrying on the research, and to take as much of it as he will hand over to us. Dr. Glazebrook.

Professor BARRETT, in reply, said: I was looking forward to the time when we should be able to hand over to the National Physical Laboratory the whole of this work, because it would be done better and with more completeness than I can hope to do it, and with much more assistance. The appliances we have used are those obtainable in an ordinary physical laboratory, while Dr. Glazebrook will bring to the experiments not only his great skill and knowledge, but also a better laboratory equipment and site than I possess. Some idea of the troublesome nature of the work in an ordinary teaching laboratory can be gained when we remember that the magneto-metric results depend upon the constancy of the earth's magnetic field —H. After some weeks of work we found that the value of this field had changed, and the results were seriously affected. This was due, we found, to an attendant placing a row of iron coal-scuttles behind a wall near the magnetometer, and some weeks' work was lost. Then there is the leakage of currents from the electric tram-lines that surround the Professor Barrett.

Professor Barrett.

laboratory, which no doubt affects the value of H. We had, therefore, frequently to re-determine the value of H, in the course of the investigation, in order to get the results comparable.

Permit me to express my own very great gratitude to Lord Kelvin for having come here this evening, especially as he is far from well, and also to say how much this research is indebted to a former student and assistant of Lord Kelvin's, Mr. Brown, B.Sc., who is now assistant-physicist in the College of Science, Dublin. Mr. Brown has throughout taken a large part of the drudgery of this work upon his own shoulders, for a good deal of drudgery is involved both in the details of the experiments and the calculation of the results. I wish, therefore, to associate his name with the kind expressions that have been used. Mr. Hadfield, whose eminence as a steel manufacturer and discoverer of new alloys of steel is well known, has devoted much time and money to the preparation of this magnificent series of alloys, and I think special thanks are due to the public spirit and also the true scientific spirit he has shown.

With regard to the question asked about non-magnetic steels, if I understood it aright, it was said that hitherto they could not be machined, and so could not be worked in the construction of iron ships, etc. This is quite true of the non-magnetic manganese steel; it is much too hard to plane or drill. But this is not the case with several of these non-magnetic steels now before you. They are much softer, especially No. 1,313, which I have mentioned. The effect of rusting, however, is serious in some of them. A question was asked by Mr. Campbell about the probable advantage of the high resistance to eddy currents of the silicon and aluminium-iron alloys. The late Professor Fitzgerald made the same remark when he heard the results of this investigation, and he said to me, "This will perhaps do away with the need of lamination in transformers, the eddy currents being suppressed by the high resistance of these alloys." But, as a matter of fact, I do not know whether in practice this will be so or not. The aluminium-iron alloy certainly does get very hot when inside a solenoid through which an alternating current is passing. When compared with iron, using the same strength of current and number of alternations per second in each case, in a given time you will find that the aluminium-iron rod is hotter than the Swedish charcoal-iron rod. The reason of that is that for a given current strength the maximum induction is much higher in the aluminium-iron, and therefore, of course, as the magnetic flux is much higher one gets greater heating; but if the magnetic induction be reduced to the *same maximum value* in both cases, then the aluminium-iron should not be as hot as the best iron, as its hysteresis loss is less.

One important point is the "ageing" of these iron alloys. On this, as yet, I cannot express any definite opinion. We all know that ordinary iron has to be annealed very frequently when used in transformers, as it rapidly loses its good qualities. You may, however, spoil your iron by over-annealing. I do not know as yet the best period of annealing for aluminium-iron; a number of experiments will have to be carried out to ascertain this point, and whether the alloy

deteriorates in use. So far as we have tried, it does not seem to alter by ageing. We submitted the aluminium-iron for some time to an alternating current, and then re-determined the cyclic curve, and it came out practically the same. But it must be submitted to a much longer and more severe trial before any definite conclusions can be arrived at, and that part of our investigation is now in progress. In conclusion, I beg to thank you, sir, and the other speakers for the kind words which have been said about this paper. Professor Barrett.

The CHAIRMAN: It is quite unnecessary, I am sure, to ask you to return your very cordial thanks to Professor Barrett for the trouble he has taken in preparing this paper, and for making the long journey he has made from Dublin in order to deliver it to us this evening. The Chairman.

The resolution was carried with acclamation.

The CHAIRMAN announced that the scrutineers reported the following candidates to have been duly elected:—

Member:

Hermann Spengel.

Associate Members:

Walter Bert Hodgetts.	W. Maxwell Stewart.
Albert Henry Marshall.	Wm. Court Parsons Tapper.
Samuel Dean Schofield.	James Edward Taylor.
Hubert Elwell Smith.	Harry Bertram Whitmore.

Russell Oswald Wright.

Associates:

Joseph Ainscough.	Ralph Nance.
C. McArthur Butler.	Walter Edwin Nicoll.
Edward Vincent Clark.	Ralph Walton Perry.
George Richard Eric Crawley	Charles C. Roberts-Wray.
Francis Henry Grace.	Gerald Rhodes Rosevere.
Edwin Rudolph Grote.	Wm. Edward Russell.
Richard B. Hungerford.	Thos. P. Shilston.
Wm. Duncan N. Morgan.	Edward Taylor.

Wilfrid Lawson Winning.

Students:

Alexander C. Anderson.	Arthur E. Laurie.
Wm. James Bell.	Walter James Percey.
Gerald S. C. Bodkin.	Henry Waymouth Prance.
John Henry Dowling.	Douglas H. Remfrey.
Arthur B. Duncalfe.	Arthur Bruce Scorer.
Chas. Bayly Franklin.	John Henry Todd Strong.
Chas. Godfrey Friedeberg.	Wm. Edmund Walden Vincent.
Chas. Edward Gunner.	Peter Wilson.

The Three Hundred and Seventy-third Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 27th, 1902—Mr. WILLIAM E. LANGDON, President, in the Chair.

The minutes of the Ordinary General Meeting held on February 13th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

John McFall Smyth.

From the class of Associates to that of Associate Members—

Arthur Herbert Blagden.

From the class of Students to that of Associates—

Thomas F. Allden.	Donald Smeaton Munro.
Walter Ings.	Francis Henry Nicholson.
Arthur Nicholl Moore.	R. P. Russell.

John Newton Arthur Houblon.

Mr. D. H. Kennedy and Mr. W. Reilly were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from The Comptroller General of Patents, Mons. E. Guarini, The Radcliffe Library, Oxford, Mr. F. C. Raphael, Mr. J. H. Rider, Mr. H. R. Rogers, and Mr. Stuart A. Russell ; to the *Building Fund* from Mr. W. W. Strode and Mr. W. R. Wynne ; and to the *Benevolent Fund* from Mr. W. E. Russell and Mr. W. W. Strode ; to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I have to announce that the Council have had under consideration the propriety of arranging a visit to some foreign part during the present year, but after a great deal of consideration it has been thought wise not to follow the precedent of last year with respect to the present year, but to pay a visit to Italy in 1903. The Council are of opinion there will be objects of very great interest to many members of this Institution there. It has therefore been proposed that a visit shall be made to that country, and Dr. Thompson,

on behalf of the Institution, has kindly placed himself in communication with Signor Colombo, who has given a very hearty response. I will ask the Secretary to read Signor Colombo's letter to you.

The SECRETARY read the following letter :—

"ROME,

"*February 21st*, 1902.

"To Professor Silvanus P. Thompson, F.R.S.

"MY DEAR SIR,—I feel greatly honoured by your letter of the 15th inst., which reached me in Rome, where I came for a few days for the inauguration of the Parliamentary Session. I am glad to hear that your Institution of Electrical Engineers will make a visit to our electrical installations during the week preceding Easter of 1903 ; and hope the season will be favourable to your purpose.

"You may be sure, my dear sir, that you and your friends will find the warmest and heartiest reception from all of us. I place myself at your disposal and at the disposal of Mr. McMillan for everything that may be thought necessary to ensure the best and most complete success of your visit.

"I will personally take charge of all the necessary arrangements for it. You have only to send me a programme of your tour, how many days you will remain, and what works you wish particularly to see, and accordingly I will prepare a detailed programme of visits, and also I will take the liberty of pointing out to you what would deserve to be seen in addition to or modification of your programme.

"There is no doubt that every one of our electricians and industrials will be glad to guide you and to open their works and installations to you ; and I will of course take care of that in time.

"Yours very truly,

"G. COLOMBO."

The PRESIDENT : I am sure, gentlemen, you will agree with me that we are very much indebted to Signor Colombo for this very hearty response to Dr. Thompson's communication. Our thanks are very much due to him. Details of the arrangements will be announced in due course and circulated amongst the members. I merely make the announcement at this early stage so that you may know that something is in the wind, and that next year we may hope to pay a very successful visit to Italy.

I am also asked to announce that Mr. Eborall's Howard Lectures at the Society of Arts in 1901 are now published by the Society of Arts, and may be purchased at the Society's Offices, John Street, Adelphi, at 1s. 6d. per copy. This most excellent series of lectures will, I am sure, interest a great number of members.

We have now three papers before us all dealing with the same subject, but each one in a somewhat different form. Each of the authors deals with the subject from the physiological side ; but in one instance one of the authors also takes into consideration what I may perhaps term its material branch. The papers are all of the deepest interest. They treat of a question of very great importance, viewed

either from a humanitarian point of view or from a material point of view. So many instances of what has occurred are brought to the surface, that I am sure they will invite and receive every consideration from all who are capable of affording us some assistance in the matter. What we are all desirous of, is that, if possible, by the investigation of the cases instanced, we may arrive at some means by which those casualties which unhappily from time to time occur may be prevented, or that we may discover some means of rendering better aid than has hitherto been in our power under such circumstances. I myself follow very much the pertinent question put by Mr. Aspinall in his paper, viz., What is it that causes the breaking up of life by electric shock? If doctors could place us upon that track, possibly we might then be able to arrive at something which would enable us to counteract it.

General Webber in his paper has incorporated certain suggestions that have been put forward for rules with a view to the prevention of accidents. Those regulations, which, as you will understand, are more suggestions than regulations, are open to discussion.

In dealing with the discussion, I would like to ask members, where they find it necessary to refer specially to any one of the papers, to refer to it under the name of the author, so that the authors may be able, when the discussion is proceeding, to take note of the points which especially refer to them. I propose to take the papers in the order in which they are announced on the card, General Webber's first and Mr. Trotter's last. Mr. Trotter has some demonstrations to follow his paper, and it will be more convenient for them to be taken last.

ELECTRIC SHOCK AND LEGISLATION THEREON.

By Major-General C. E. Webber, C.B., R.E., Past President.

The object of this paper is to bring home to the Institution and suggest discussion—

First, on the scientific aspect of the subject of "electric shock."

Second, on the liability to exposure to electric shock in the electrical industries.

Third, on the information, under which the Government was led to place the industry in this respect under the incidence of the Factory Acts.

Fourth, on the events which led up to the inclusion of electrical generating and transforming stations in factory legislation.

Fifth, on the desultory nature of the resistance to the measure by the industry, and on the want of co-operation by, and organisation of, all parties interested.

Sixth, on the lessons to be learned for future guidance in connection with probable legislation, with reference to whatever results, if any, the action of the Institution and of other bodies, may have secured in this particular case.

The Shock.

In ordinary speech it is customary to attribute the results of electric shock, if fatal, to failure of the heart's action. Electrocution is the application of a powerful electric current to the nerve centres. But like all these questions which are bound up with the whole subject of the generation and storage of energy in physiological structures, the ordinary expressions used are very far from being suggestive of what actually subsists. For instance, "failure of the heart's action" is an expression, to my mind, which is wholly misleading; although harmless, except, in that it points the student into a totally wrong path for thinking out what really occurs. The underlying fallacy is that the heart is a pump, in the sense of being the sole source of energy in a system of hydraulic distribution, and that the energy expended in the circulation of the blood is developed only in the heart. No engineer can accept this theory for a moment. No physiologist who is always face to face with the perfect balance and distribution of forces in what we call "nature," if he is also an engineer, but must see the fallacy in such a proposition.[1]

It is quite clear that the energy expended to keep the blood circulating acts at every part of the blood's path, and that the share borne in the act of contraction and expansion of the heart is *only* a share for the purpose of the special duty the heart has to do, and probably not greater in proportion to the volume of blood dealt with at each pulsation within the heart, as compared with the whole volume of blood in the body. Any engineer at once appreciates that

[1] Helmholtz estimated that the effort of the muscles of the heart in contraction and expansion is expressed by the raising of its own weight—nine ounces—through 20,250 feet in one hour. His conclusion was derived from the measurement of the blood pressure in the large passages.

theoretically energy is most usefully applied at the points where the friction is greatest, that is, at the thousands of points where the blood has to pass through a capillary, the channel in the membrane of which is so small in diameter that the corpuscle has to be elongated to get through it. Remember, every particle of blood must pass through one of these minute conduits more than twice in a minute. Approximately speaking, the greater portion of the energy used in maintaining the circulation is expended at the myriads of points where the capillaries are situated.

It is not the object of my paper to attempt to follow the history of the generation, storage, and distribution of energy within a living organism, but it is my object to draw the minds of my audience to any evidence that may exist in favour of the theory that the arrestation of the circulation is due to some check or stoppage of the distribution of energy to all parts of the path of blood circulation, notably to the capillaries, and most notably of all, to those capillaries which are cutaneous.

It is at some point on the skin that electric shock is communicated. Are the further effects on the mass one or other of the following, or, are they due to both ?—

(*a*) By means of a nerve conductor direct from that point on the skin to a centre, where some vital nerve structure is shattered ; or

(*b*) By being distributed over the whole surface of the skin, destroying the nerve power of the capillaries, and thus arresting the circulation at thousands of points.

These, and similar questions connected with the engineering of physiological structures, are well worthy the attention of the thoughtful electrical engineer.[1]

[1] It is true that the engineer has not much practice in the flow of an homogeneous liquid through a system of elastic tubes, as has the physiologist. But his studies lead him to understand the conditions of, intermolecular friction, surface adhesion, effects of surface on flow of irregularities, eddies, fluid viscosity, and even the effects on flow of the elasticity of the walls of tubes. It will not be uninstructive to him to study the journey of the blood, which makes an entire circuit during the time occupied by about 28 pulsations. He may realise the object of, and the work done by, pulsation, subject to the effect of the resistance to flow which lies in the passages through the membrane situated in every capillary, although the length of such passage is only $\frac{1}{350000}$ of an inch. And as an electrician he may learn something from the study of the process of dialysis in the membrane, accelerated as it doubtless is by the presence of electrodes on each side of it.

A reference to a few experiences of which we have record may assist our consideration of this interesting question.

It was in the year of my occupation of the Presidential chair (1882) that Dr. Stone and Dr. Kilner turned our thoughts to the action of electricity on the human organism, for curative not destructive purposes. The paper refers to the knowledge on the subject recorded in the proceedings of the Congress at Paris in 1881, and to the experiments on resistance of skin and tissues of Professors Eckhardt, Frankland, and Matteucci. Generally they described these curative currents as having an E.M.F. of 2 volts and 20 to 30 milliamperes. The figures given showing the result of experiments on the variation of resistance of the human body are very interesting.

In 1884 Dr. Stone read us a paper on the physiological bearing of electricity on health, in which he also referred to death by shock, and he insisted on going further afield than the accepted theory of simple shock or syncope, and described *post-mortem* appearances resembling the thrombosis or coagulations of blood in one of the larger vessels as being as accessory to death causing asphyxiation.

As regards the resistance of the skin in health, Dr. Stone gave evidence of his having brought it down to 500 ohms by special treatment, all of which points to the path of least resistance being in the pores, and of its variation under a state of disease or when any one's occupation entails metallic impregnation of the skin.

In 1883 Mr. Crompton wrote to the Institution on the subject of "shock," due to what he called the "extra current," caused in an organism when it forms a shunt to a normal comparatively low current. The ratio between the "normal" and the "extra," he wrote, is probably directly proportionate to the magnetic moment of the whole circuit. He drew attention to the innocuous nature of the shock received when adjusting arc and glow lamps in parallel, as compared with the current due to the effects of "magnetic change" in a high-tension series system.

As regards the conditions, when any part of a human organism forms the path of a current, he came to the conclusion, that, with what was then known as a continuous current, "safety," *i.e.*, freedom from painful injury, with a

quantity of, say, 25 amperes, lay "between the limits of 300 and 400 volts."

In 1884 Mons. C. M. Gariel, in *L'Électricien*, mentions the results of the examination of the bodies of two men who were killed by an alternating current of 500 volts.[1] He considered that the electricity acted indirectly by partly suspending the action of the nervous system, the suspension causing death. In the case of one of the men killed the heart was found to be empty, in the other case it was full. He argued "that it was far from having been proved that in the action of electricity on organised beings, it is the intensity of the current which can be taken as a measure of the effects produced."

In 1887 Mons. A. d'Arsonval, for the third time, took up the subject of the physical effects of electric shocks. His researches were based on the suggestion that different physiological effects might be expected from a static machine, from a battery, from dynamos for producing continuous and alternating currents, as well as with the apparatus used for transformation. He referred to phenomena and to injuries which varied with the conditions.

He considered that electricity causes death in two ways, namely, by—

I. Direct action, causing mechanical disruption and distortion of the tissues.
II. Indirect or reflex action, acting on the nerve centres.

He concluded that in the first case death is certain; that in the second, often a condition is produced in which consciousness may be restored by practising artificial respiration.

With the appliances at the disposal of himself in 1887, and of other scientists whom he quotes, such as Berlioz, M. d'Arsonval's researches were those of a most distinguished physiologist, who for the first time found himself handling machinery, the energy obtainable from which was very large, as compared with the small laboratory generators of the past, the use of which had been studied more for constructive than destructive purposes.

[1] Known as the Tuileries Garden accident.

At any rate at that time he felt himself constrained, as the result of his researches up to that date, to urge the immediate use of artificial respiration in case of syncope from an electric shock.

These observations led in 1894 to the issue by the French Minister of Public Works of a set of instructions for the immediate handling and treatment of the bodies of those who have been subject to electric shock. This treatment is very similar to that used on the persons of those who have been suffocated.

They were drawn up by a committee of the Academy of Medicine, of which M. d'Arsonval was a member. They have been more or less imitated here and in the United States.

In a pamphlet written in 1888, entitled, "The comparative danger to life of the alternating and continuous electric currents," by an electrical engineer, Mr. Harold P. Brown, of New York, we find reference to the sacrifice in that country of so many lives through, as he stated, "criminal economy in electric lighting," that he considered legislative control of the subject to be imperative.

Previous to that, I think, it may be safely asserted that "careless methods" were the rule in the United States. The danger was emphasised in the case of the use of high-tension currents for the wide distribution of arc lighting, through the excessive climatic wear and tear of a rigorous climate on the plant in overhead lines, and, through the habit of practically grounding circuits by providing badly insulated or insufficient metallic return or by neglecting leakage when theoretically they were so provided.

Mr. Harold Brown largely dwells on the difference in danger to life from the shock of an alternating and continuous current. He complains of the violence of the opposition to this and the personal abuse to himself of the "representatives of the alternating companies." The controversy, which extended over a considerable period, was stimulated by the commercial interests of the advocates of alternating current working.

Experiments on animals, which in this country would come under the control of the Vivisection Acts, were made. These, and other officially made experiments, determined

methods for the execution of criminals by electricity which became law in the United States in 1889. The use of the alternating current for electrocution was decided on, supported by a report of a Medico-Legal Society Committee. At the same time the effect of the controversy was to push on protective legislation in the United States.

In the meantime, with rare exceptions, the pioneering of electrical distribution in these Kingdoms was begun under engineers who had made up their minds that no quick returns and no immediate evidence of activity in enterprise would justify superficial or unsound work in systems of distribution. That the cost thus entailed on undertakings at the outset appeared prohibitive and retarded progress, goes without saying. Hence the startling difference between the deadliness of the alternating as compared with the continuous current has never been so prominently before *our* public as in the United States.

In the experiments that were made in 1888 in the United States on animals, such as dogs, horses, and cows, the evidence sought for has apparently been to discover roughly what would give pain, or injure without killing, or, actually the conditions of current which would kill and in doing so would give as little pain as possible. As a preliminary to really scientific research those trials are so far of use, but they are necessarily very crude. For instance, the mere fact that tests of the comparative resistance between contact on the fore and hind legs of dogs of almost similar weight varied between 8,000 and 200,000 ohms[1] showed that all the conditions of skin surface were not investigated. In respect to insulation, the construction and manner of attaching the poles, suggested conditions capable of producing considerable differences of resistance. In the case of a horse the attachments were immediately above the knee of each foreleg. In that of a calf one electrode was applied to the forehead between the eyes, the hair being first clipped, the other was applied to the left side of the spine, back of the shoulders. Between the electrodes in several cases the resistance was about 1,300 ohms. Death was inevitable with an alternating current at 750 volts applied for five seconds.

As, in these experiments, killing was what was wanted, all delicate investigation was omitted; for instance, the actual

[1] Dr. Stone in 1884 spoke of the resistance of the human body, which varied between 500 and 100,000 ohms, as entirely due to the condition of the skin, which he referred to as an "epidermis of gutta-percha."

resistance of the skin which covered the bodies of the subjects while still alive; also, the resisting power of each part of the skin, for example, under the conditions of what is understood as "pores open or closed," were not investigated.[1]

Throughout, the experimenters assumed that the current travelled *through* the body from one electrode to the other. They also jumped to the conclusion that in its passage it was "diffused in the tissues," and that it thoroughly "permeated" the brain and nerves. In fact, they knew little about it; all they knew was that they "killed." As in the case of the discussion on a paper by Mr. Wyman on electrocution, which took place at the meeting of the Convention of the American National Electric Light Association in 1889, every consideration was subordinated to the minimising of "cruelty."[2]

In that case those representing the electrical engineers of the United States had to deplore (as we lately have had reason to do), that, matters of more pressing interest had intervened to prevent them considering the question until after legislation had been decided on in New York State.

In 1891 there is a paper in our Journal on electrical shocks by Major Cardew, which in a very accurate manner discusses the degrees of danger, not from high pressure, *per se*, but from the point of view of the greatest quantity that can be passed through an organic body without danger. He described the then conditions of scientific opinion to be, that the effects of the passage of a current as regards injury to skin or tissue is probably proportional to the square of the current, and that alternating currents, in addition, have special paralysing effects on the nerves.

Professor Fleming, in his remarks in the discussion, went,

[1] Lately some very careful experiments have been made in France as to the results with the use of electrodes of different metals and covered and moistened in different ways. These will be found in the *Comptes rendus* of the Electro-therapeutic Section of "L'Association Française pour l'avancement des Sciences."

[2] There are many careful thinkers who ascribe the symptoms which have followed electric shock more to *fright* than to actual interference with the working of the system that upholds our vitality. They point out that actual personal injury, say, from the distribution of gas, is much more frequent in proportion to the generation and distribution of that article of manufacture as compared with that of electricity. How far this danger will be increased by the distribution of gas which contains a large proportion of carbon monoxide for industrial purposes remains to be seen.

I think, one step further, following a sound "trail," and suggested the presence of electrolysis of the fluids of the body with powerful continuous currents. Besides, he opened out the view that all physiological organisms are "both like a condenser and like an accumulator."[1] The personal experiences of Mr. Addenbrooke and Mr. Mordey, with conductors carrying a high tension alternating current, described by him on that occasion, are also interesting.

There is an interesting article[2] by Dr. A. M. Bleile, Professor of Physiology in the Ohio State University, on the cause of death in electric shock, which brings the subject a stage nearer the contention I have put forward at the beginning of my paper. He killed the dogs on which he operated, easily, with an alternating current having a periodicity of 130, at an E.M.F. of under 100 volts, and under 1 ampere. The product of the volts into the amperes, into the seconds, (joules) is surprisingly small. The condition of the heart and arteries, as found by immediate autopsy, led him to the "exclusion of a direct effect upon the heart."

By administering the shock to animals under the influence of atropine, the theory that the current immediately strikes the pneumogastric nerve stimulating those fibres which control the heart had, in his opinion, to be abandoned, because the animals were not rendered more resistant by the drug.

He found that immediately after death incisions into the body were not followed by bleeding, and that the arteries were contracted. This suggested to him that the current had acted on the arteries through the nerves which control their diameter. He then dilated the arteries in the subject under experiment with the hypodermic use of nitro-glycerine. A current (namely, 50 volts ·24 ampere for four seconds) administered under the influence of this drug, which should have caused death, was not fatal; the effects passed off and there was recovery. However, 97 volts ·54 ampere for one second, killed. Under the influence of the inhalation of the nitrite of amyl, a substance which produces the same effect, namely, dilation of the arteries, fatal shocks were applied without producing death. Dr. Bleile concludes :—

"It would appear, therefore, that death in electric shocks

[1] Mons. M. G. Weiss, in *Journal de Physique*, 1897, describing the polarisation of organic tissue as proportional to their length and inversely as their section, compares a muscle to a mass of particles which polarise, "thus acting as small accumulators."

[2] *Transactions of the American Institute of Electrical Engineers*, August and September, 1895.

is entirely due to the fact that the current produced a contraction of the arteries through an influence on the nervous system, and that this constriction throws in such a mechanical impediment to the flow of the blood as the heart is unable to overcome."

I hope I may be pardoned if I make so bold as to suggest, that where effective contraction takes place is in the channels of the capillaries, and, that it is the afferent nerves that actuate them which are locally paralysed.

By the expression "*electric shock*" the Factory Inspectors under the Home Office have sought to define the physical injury from contact between the animal structure and opposite poles of electric conductors. Legislation has now been brought into operation at the instigation of the Home Office in the Workshops and Factories Act of 1901, by which it is sought to afford protection to some persons whose employment exposes them to the possibilities or probabilities (as the case may be) of such contact.

It should be interesting to electrical engineers to trace how this enactment has come about, and also to discuss its wisdom, and whether and how far it is effective for the benevolent purpose for which it is intended.

Legislation.

The origin of the Factory Acts was to provide protection for those who, owing to necessity and force of circumstances, could not protect themselves. It is a question whether, when that was achieved, the benevolence of later legislation has not carried the theory too far, and has not reversed the effect of the original motive that stirred the strong to protect the weak. I mean whether it was not quite sufficient to have provided means of protection for women and children and to have left full-grown men with their powerful trade organisations complete independence to accept employment under any conditions they please.

If examples in which various kinds of work can be performed with every kind of personal protection from injury which science can invent were necessary, such precautions should, I venture to suggest, have been first made the rule in State workshops, such as dockyards and arsenals. There is

little doubt that if the accident insurance societies had then been brought under State supervision, and the rates of insurance settled inversely as the employer's precautions were more perfect, the question would have settled itself in a way far more in the real interests of the protection of the person of the employed than by the elaborate, complicated, and unequal, system of inspection that has been inaugurated, the incidence of which tends more and more to unnecessary expenditure on the inspection itself and on empirical precautions, and, to relieve the employers from real responsibility.

No one can read the elaborate annual reports of that earnest body of public servants, the Factory Inspectors, without being impressed by the evident (and to be expected) pressure that is put on them to spend their intelligence on elaborate speculation as to the mechanical cause of accidents and on expedients to prevent them. These are necessarily not the outcome of the experts in the trades, and they often leave entirely out of sight the limitations put on the industries affected.

In 1895 a Departmental Committee was appointed by the Home Secretary to report as to the effect on the health of operatives of certain miscellaneous industries, trades, and processes, and in the list of about twenty dangerous ones was included "Electrical Generating Works." They issued reports in 1896, 1897, 1898, and 1899, and in their interim report of 1897 they dealt with electrical generating works. Four years later, in 1901, we have had the legislation in consequence of that report. Electrical transforming places, which are included in the Bill, seem to have been an afterthought.

That part of the Factories and Workshops Act Amendment Bill as *drafted* by the Home Office to bring electrical generating stations within its operation was as follows :—

"Clause 45.—There shall be added to the list of non-textile factories in Part I. of the 4th Schedule to the principal Act the following: Electric stations, that is to say, any premises in which electric energy is generated or transformed, either for the purpose of supply by way of trade, or for any purpose incidental to any other business except the transmission of signals or messages."

In the natural course a Bill of this nature came auto-

matically at its earliest stage under the observation of the London Chamber of Commerce, but it was only through that fact, the writer, who is a member of the Electrical Section of the Chamber, moved the Council of the Institution of Electrical Engineers, on the May 24, 1901, to take it up and to refer it to a Committee.

The motion was—

> "To ask leave of H.M. Secretary of State for the Home Department that a deputation of the Council of the Institution of Electrical Engineers may approach him to urge and explain their views on behalf of the electrical engineering profession, viz., that electrical transforming stations should not be included in Clause 45 of the Bill now before Parliament, by which it is proposed to bring the places in which energy is transformed under the same regulations and inspections as the stations in which it is generated."

The Committee nominated was Sir Henry Mance, Mr. H. W. Miller, Mr. W. H. Patchell, Mr. Alexander Siemens, Mr. R. P. Sellon, Mr. R. W. Wallace, and Major-General Webber. On June 3rd the Committee met.

A letter from the Council of the I.E.E. to the Secretary of State was written on June 25, 1901, to the effect, that, they had carefully considered the probable effects on the industries which are engaged in the public supply of electrical energy by the inclusion amongst the definitions in the Factory and Workshop Acts Amendment Bill of the premises in which electrical energy is generated and transformed.

It was pointed out that the Institution represented the interests of a very large number of members—nearly 4,000—all of whom were more or less engaged in the generation, transformation, and application of, electrical energy. Fear was expressed that if the industry were brought, as proposed, under the terms of the Factory Act, such action would prove detrimental to its progress, while it could in no way modify the responsibility of the employer in respect of the Employers' Liability Act.

The entire abandonment of the inclusion of the proposed Section 1 of Clause 45 as quoted above was urged, with the alternative that, if this course could not be followed, such provision might be made as would insure to the industry, through the medium of the Institution of Electrical Engi-

neers, that, in case of any irreconcilable difference arising between a factory inspector and a statutory electrical undertaker as to any requirement of the former, the same would become a subject of special reference to an expert, in which reference the Council of the Institution would have a recognised status to watch the inquiry on behalf of the industry as a whole.

To the above the Council received a reply dated July 13, 1901, to the effect that the Home Secretary "attached the greatest possible importance to the support and co-operation of the Institution of Electrical Engineers, and that while he could not omit from the Bill the proposals which it contained on this subject, and which only declared definitely the law as now generally accepted,[1] he would certainly be prepared before applying any new regulations to electric works to consult the Institution." He added that "he would also see that in any action taken as to the enforcement of such regulations the Factory Department should have the assistance of expert advice."

Preliminary Investigations.

At this stage let us go back for a little space to what had occurred in 1897 when the Dangerous Trades Committee reported on electrical generating works. The Committee was composed as follows: Mr. H. J. Tennant, M.P., Mrs. M. S. Tennant, Dr. Oliver, F.R.C.P., Commander H. P. Smith (retired), R.N., Inspector of Factories. Added to their number was Mr. C. V. Boys, F.R.S., whom as a Professor of Physics many of us know. They stated that one or more of them had visited twenty-six generating and sub-stations, that they had examined witnesses, and that they had been assisted by Major Cardew, Sir David Salomons, Professor Ayrton, Dr. Hopkinson, Professor Kennedy, Professor S. P. Thompson, Mr. F. Bailey, and Mr. Swinburne. The preamble of their report is an excellent description of what constitutes an electrical generating station, and of the process of manufacture of, what, the magistrate at Bilston later on in 1899 "believed to be an article of commerce, when generated by way of trade and

[1] Though, no doubt the law officers of the Crown were consulted, apparently the only support of this statement is the Bilston case of 1899, referred to further on.

for purpose of gain," and therefore an "article within the meaning of the Act."

There can be little doubt that the above-named description, however popular in its language, is too technical to have been worded by any other member of the Committee than Professor Boys. Similarly in a description of the dangers to shock of working there is every evidence that it could have been drawn up by no one but an accomplished theorist. The only scientific work of any other member of the Committee which is actually identified is that of Dr. Oliver, who carried out some experiments on animals with the view to ascertaining the actual cause of death following an electric shock. There then followed twenty-two recommendations of the Committee, for regulations, which are given below *in extenso.*

Regulations Proposed in 1897 by the Home Office Committee.

(i.) The frames and bed-plates of all generating machines shall be efficiently connected to earth.

(ii.) The rails fencing dynamos or other generating machines *shall be made of wood* or other non-conducting material.

(iii.) All terminals, collecting brushes, main connectors, parts of dynamos, motors, or other appliances, to which neither Regulation No. (vi.) nor No. (vii.) applies, shall be so placed, covered, or fenced, with non-conducting materials, that no person can touch accidentally, either with his body, clothing, or any conducting tool, two parts differing from each other by an amount which constitutes a high pressure. This rule is to be read in connection with No. (iv.)

(iv.) The floors of all places where it would be possible in make connection with metal at high pressure shall be covered with an insulating mat of suitable material, and kept in a state of efficient insulation.

(v.) The material used for wiping or cleaning, the commutator strips, or collector rings, or dynamos, motors, or rotary converters of any form, shall be applied by means of an insulating handle.

(vi.) In switch-rooms and on the front of switchboards, the main switches, main fuses, main terminals, omnibus bars, and all other metallic parts, shall be insulated or arranged in such manner as to render it impossible for any person by accident or inadvertence to touch them.

(vii.) The backs of all switchboards shall be kept closed, except for the purpose of alterations or repairs. When such work has to be carried on either at the back or at the front of switchboards, the following regulations shall apply :—

a. No person except a skilled electrician, or a workman under his personal and immediate supervision, shall be employed when any part is at high pressure.

b. No extensive or serious repairs shall be executed upon metal which is at high pressure.

c. Where the alterations or repairs are not of an extensive or serious character, all metallic parts at high pressure shall be covered with an insulating cap or protected by some form of insulating covering, only one part, or several at the same pressure, to be exposed at any one time.

(viii.) All switchboards erected after the application of these Rules, shall have at the back, a clear space of *at least four feet.* This space shall not be utilised as a storeroom or lumber-room, or be obstructed in any manner.

(ix.) Any person at work upon a cable or portion of the mains under high pressure shall wear indiarubber gloves on both hands.

(x.) All aërial high pressure conductors in factories or workshops shall either be insulated over their entire length, and supported at such frequent intervals that in the event of breakage they shall not come within reach at places where persons are liable to pass or to be employed, or shall be so placed and arranged as to comply with the requirements relating to such wires in streets enjoined by the Board of Trade.

(xi.) The gloves shall be supplied by the occupier, and it shall be the duty of the manager to see that they are in a proper state of repair, and are worn by the workpeople.

(xii.) No examinations, repairs, or alterations necessitating the handling of mains, wires, machines, or other apparatus, shall be carried on except in cases of urgent necessity, while such parts are under high pressure, and all such work shall be done under the personal supervision of an electrical engineer or competent manager or foreman.

(xiii.) Where operations are being conducted upon mains from which the current has been cut off, the switch shall be locked, and precautions taken that it shall not be unlocked except by the person in charge of the station, on his being satisfied that the danger is at an end.

(xiv.) Every vessel used for lubricating purposes shall be so constructed that it cannot act as a conductor between the hand and anything touched.

(xv.) Metal transformer boxes shall be efficiently connected to earth, and so constructed that in the event of "running to frame" the earth connection will not be broken by the removal of the fuse box or any other part of the box.

(xvi.) Transformer cases, iron ladders, and all permanent metallic parts contained within the transformer chamber and not forming part of the electric circuit, shall be metallically connected together.

(xvii.) All holes in transformer cases through which high pressure conductors pass, shall be lined or bushed with suitable and effective non-conducting material.

(xviii.) All high pressure connections within a transformer chamber shall be so protected with insulating material that it shall be impossible to touch them.

(xix.) Switches which can be conveniently operated from the outside

for cutting off both the high and low pressure connections of the transformers, shall be fitted in all transformer chambers erected after the application of these Rules, and in all existing chambers, unless it is proved to the satisfaction of His Majesty's Chief Inspector of Factories that such an arrangement would be attended by special difficulty.

(xx.) Each post or support where series arc lighting is employed shall be provided with means for completely disconnecting the arc lamps from the mains, without disturbing the action of the other lamps.

(xxi.) All persons engaged in electrical works shall be made fully aware of the dangerous parts of the machinery, cables, and their connections, and shall be practically instructed in methods of artificial respiration—that known as SYLVESTER's is both simple and efficacious. Rules for artificial respiration, and for the restoration of persons apparently killed or injured, shall at all times be kept affixed in the station. All persons engaged in the works shall thoroughly understand these rules, and be capable of putting them into practice. In the event of a person being rendered unconscious by an electric shock, artificial respiration shall, on the careful removal of the body from its electrical contact, be at once resorted to, and a qualified medical man immediately summoned.

(xxii.) All accidents occurring in generating stations or transformer chambers shall be notified according to the provisions of Section 18 of the Factory and Workshop Act, 1895.

It is trusted that these suggested rules will be subject to criticism in discussion, but I would ask station engineers to consider—

a. The power of rendering it impossible for any person inadvertently to touch two parts of all apparatus which differ opposingly under high pressure, as laid down in iii. and vi.

b. What constitutes a "skilled electrician" in vii. If he takes a "workman" with him behind a switchboard, is he to be responsible for the results of the man's possible carelessness? In the same rule what is the meaning in (*c*) of the words, "only one part or several at the same pressure"?

c. Rules xiii., xv., xvii., xviii., xix. and xx., which all refer to parts of a system of distribution, that has nothing to do with generation or manufacture, except, in so far as lies in the contention, that transformation is to be regarded as part of the process of making electricity for purposes of sale.

ELECTRIC SHOCKS.

By F. B. Aspinall, Member.

I bring this question before the Institution principally with a view of obtaining particulars of severe electric shocks which have not proved fatal; and therefore trust that any one who, from his own experience, can give particulars of cases, will kindly do so. My reason for trying to obtain this information is that I believe we, as electrical engineers, can render great assistance to the medical profession by doing so; and possibly by enabling them to tell us some better methods of rendering aid to those who, unfortunately, are the victims of accidents, we shall be well repaid.

I have been personally deeply interested in this subject for some years, and have collected from my own experience and that of friends both in this country and abroad, particulars of as many cases as possible. I have also, whenever I could, made it a rule to see the man who received the shock, and also any witnesses. All cases, therefore, which I have chosen as of sufficient importance to mention in this paper are, to the best of my belief, thoroughly accurate and reliable. In obtaining this information I have been much struck by the fact that it is most difficult to obtain a really accurate description from the victim or witnesses of what actually does occur, and this can hardly be expected when one considers the circumstances; but still, if I only mention what they are absolutely certain about, these cases can be taken as fairly typical.

I should like to say that, not being a doctor, I have no medical knowledge, and therefore trust that any medical men reading this paper will take this into account if I say anything which to them may seem absurd.

In discussing this question with my personal friends in the electrical profession I find there are many points upon which more information is required, and I think these points may be best summarised as follows:—

1. Is every one equally susceptible to an electric shock?
2. Is a person suffering from disease more liable to be

fatally injured by an electric shock than a person in good health ?

3. Does the physiological condition you are in at the time you receive a shock make any difference ?
4. Does the path which the current takes through the body have any effect as regards the shock proving fatal ?
5. Does the question of contact made, and whether burning takes place or not, have any effect as regards the shock being fatal ?
6. Can a person receive a fatal shock without giving the cry, and also can he speak after receiving a fatal shock ?
7. Is an alternating or a direct-current shock more likely to prove fatal ?
8. Cannot the Medical Profession give us some more certain method of saying whether a man is dead or not ?
9. Cannot something more be done than at present to help those who receive a severe shock ?

I will now proceed to discuss these points separately.

1. *Is every one equally susceptible to an electric shock ?*

In considering this question, I believe I am stating the opinion of the medical profession when I say that there is no absolutely reliable proof whether every one is equally susceptible or not. Dr. Oliver, in Allbutt's *System of Medicine*, vol. v., page 856, says : "We have no positive proof that one individual is more susceptible to an electric shock than another. It is, as already stated, rather a question of the amount of current, and whether it wholly enters the body."

My own opinion is, and I hope to prove it in this paper, that not only are different people differently affected, but the same person under different conditions does not feel the same. Of course, if one could obtain two people alike in every respect and subject both of them to exactly the same voltage and current, and also in every respect get the same conditions, no doubt they would both feel the same, although they might describe it differently ; but when it is considered that moistness, callosity, and condition of skin, nervous

temperament, the path which the current takes through the body, health or disease, drunkenness or sobriety, whether the sufferer is awake or asleep, area, the excellence and nature of contact, familiarity with shock, and no doubt other causes, as I shall point out later on, all play most probably an important part in deciding what one feels, I think my opinion will be accepted.

2. *Is a person suffering from disease more likely to be fatally injured by an electric shock than a person in good health?*

As an electrical engineer this is a most difficult matter for me to discuss; but from cases which have come under my own observation, and which I have heard of from friends, in whose veracity I can place the most implicit confidence, I think I can prove that this question is of the utmost importance. Some years ago a number of friends were in the habit of measuring their resistance periodically, and it was found that one man was always the lowest, although they all varied. This man was also abnormally sensitive to an electric shock, as he could feel even so low a voltage as that from three Leclanché cells. It was afterwards found that he was suffering from kidney disease, and although I should very much like to measure the resistance of others similarly affected, I am afraid to do so in case I might injure them. This seems to indicate that the resistance of the body may be altered by disease, and it is most probable that the skin, by fulfilling the functions which by rights belong to the kidneys, had a lower resistance due to the impurities thus removed from the body. (It is well known that in kidney disease the doctors give medicine to make the skin help the kidneys.)

In a central station I was connected with, it was the habit of the men to give an electric shock from a magneto-machine to visitors, and although it was found that different people seemed to feel differently, yet one boy could stand more than any one else. He was, however, unfortunately of weak intellect. Another case of which I have heard was at a bazaar, where money was placed in a bowl of water charged from a Ruhmkorff coil. One woman took the money out every time, and had to be paid to go away as she nearly made them bankrupt. She also was of weak intellect. No doubt this insensibility was due to the brain being affected.

It appears, therefore, fair to say that a diseased person may be either more or less susceptible according to the disease he may be suffering from.

3. *Does the physiological condition one is in at the time a shock is received make any difference?*

The first point which naturally occurs to one is, does a person in a heavy perspiration stand a better chance than one who is in a normal condition? and to illustrate this, I think I may quote the following case:—

"T." had been doing very heavy work which made him perspire freely; to rest himself he sat down on a transformer, which was earthed, and in leaning back his head touched an inner terminal; as the outer was earthed he received a 2,000-volt shock. The man was wearing a thick flannel shirt, which was wet with perspiration. The result was that he received a most severe shock, a hole being burnt in his trousers, and the back of his head and buttocks were severely burnt. This man, I think, should have been killed, but he was not even insensible. Surely this seems to show that the sweat shunted the current, thus saving his life; although the burning probably protected him, as I will show later on.

Again, would a man, when drunk, be less liable to be fatally injured? and to illustrate this I give the following case:—

"F." was working in a transformer station as a labourer, and touched an inner terminal with one hand and an outer with the other, the potential difference being 2,000 volts. It was found out afterwards that the man was a heavy drinker, and was under the influence of drink when he received the shock, which did not even make him insensible. It is only fair, however, to state that his hands were exceptionally callous, due to the fact that he had been working as a gas stoker, and also that his hands were severely burnt. Personally, however, I think the man received quite enough to kill him, and his being drunk had something to do with his not being killed.

Next, are persons less liable to be killed when they are asleep?

Some years ago I was carrying out a contract which necessitated all the work being done at night. One of the men employed was always going to sleep, so the other men

as a practical joke gave him a shock, whilst he was in this condition, from a magneto-machine capable of ringing through 30,000 ohms., but although they tried all they could he did not wake. As they thought this was peculiar the men called my attention to it, and I personally saw him receive a shock without taking any notice of it. I may also say that I arranged for my assistant to give me a shock when I was in bed asleep, and although two witnesses guaranteed he had done so, I felt nothing. Illustrating this, I should like to mention the following case:—

"B." was stationed to watch a cable under test charged to 5,000 volts, and going to sleep fell on to it. He was most severely burnt about hands, but was not killed.

Of course, with so few cases it is impossible for me to say that my deductions are absolutely correct, but I bring them forward as I think they are of profound interest both to the electrical and medical professions.

4. *Does the path which the current takes through the body have any effect as regards the shock proving fatal?*

Although I have been present in three cases where a doctor was called in to attend to a man who had received a severe shock, I have never been asked where the current entered and left the body, and this, to me, has always been a complete puzzle, as amongst all electrical engineers I know it is a firm belief that the path which the current takes is of the utmost importance, and therefore in handling high-tension apparatus we always try to make contact in such a way that no vital part is directly in the circuit.

To illustrate the different paths the current can take I will give a few cases which have come under my notice, and also what the victim felt most:—

Hand to hand	Blow in chest.
Right hand to right foot ...	Nothing.
Right hand to left foot ...	Nothing.
Right hand to both feet ...	Nothing.
Left hand to left foot ...	Blow in back of neck.
Left hand to right foot ...	Blow in back.
Left hand to head	Blow on top of head.
Head to buttocks	Could not ascertain if anything was felt.

Of course I cannot say why they should feel differently, but I bring these facts forward, as perhaps the doctors can give an explanation. I think, however, it proves that different organs of the body are affected. Dealing with this from actual cases:—

"D." was oiling an alternator, and touched the inner brush accidentally with his elbow; his right foot was on the earthed frame of machine, and his left foot insulated. The pressure was 2,200 volts, and although he gave the cry, and was sensible till the circuit was broken, he could not get away. He remembered them running to shut the machine down, but became insensible when this was done, and was treated for forty minutes by artificial respiration before he showed any signs of life. One would have expected this man to be killed, but it is only fair to say that he was badly burnt on the elbow and the foot.

"J." was adjusting an arc lamp. He had his left foot earthed, and with his left hand touched the carbons. I am unable to state the number of volts that he received, as I could not ascertain where the current earthed; but he was killed. There was only a slight discoloration noticeable, and he was not burnt.

I will discuss the question of burning later on, but I think it is a fair conclusion that the left side is more vulnerable, and I believe the reason is that the valves of the heart on this side are more easily damaged.

To my mind these cases prove conclusively that the path the current takes is a most important factor.

5. *Does the question of contact made, and whether burning takes place or not, have any effect upon a person's chance of being killed?*

In my opinion the question of contact is perhaps the most important of any which occur when a person receives a shock, and I should like to go into it rather minutely. In our ordinary every-day work perhaps the question of contact receives more attention than anything else, as not only is it a question of good contact, but the area of contact must be sufficient to carry the current. Now, when a man receives a shock this is equally true, and although it might be safe under ordinary conditions to work with even a high

voltage, yet if he really did his best to kill himself he could most probably manage it with even a small voltage, provided he had a sufficient area of contact.

To illustrate what an important part this area of contact plays, I had my resistance measured holding a No. 20 B.W.G. copper wire between the finger and thumb of each hand, and afterwards I connected these two wires to two pennies, and held them in the same way. With the pennies my resistance was 20,000 ohms lower. I therefore think if the area of contact were only sufficiently large, the resistance would be practically nothing. Of course, if the skin were wet, the area necessary to get no resistance would be much less, but as one does not work with wet hands, I need not consider the question. On the other hand, if the skin were oily it would be much more.

Another point on which I would lay particular stress, is that the area of contact to get the same resistance in different persons would not be the same, and even with the same person in different parts of the body the area of contact would have to be changed. To illustrate this I measured the resistance of six people, picked haphazard, from thumb to thumb, and although I was careful to obtain what I believe was the same amount of contact in each case, yet—

A	measured	30,000	ohms.
B	„	50,000	„
C	„	60,000	„
D	„	60,000	„
E	„	100,000	„
F	„ over	100,000	„

this being due most probably to different thickness and moistness of the skin. As regards the same person, I had my resistance measured from thumb to thumb, which gave 100,000 ohms, but from heel, where the boot rubs, to big toe, I got 200,000 ohms, although in each case I believe the same contact was made.

The question of area of contact also plays an important part from another cause, as, if the area is small, the chance of burning is largely increased, not only from the fact that heat is generated at a bad contact, but that it is easier to form an arc, which causes the burning to be still more

severe. I shall discuss the question of burns by alternating- and direct-current later on, but a direct-current burns much more severely, especially at the positive pole.

No doubt it may be questioned why I am laying so much stress upon a point which is thoroughly understood by every one, but my reason for doing so is that I believe this question of burning is a wonderful provision of nature to protect us against fatal shocks, as the burning not only numbs the nerves, and thus prevents us feeling, but will also, I believe, be found to increase the resistance, thus preventing the current passing. It is impossible for me to experiment on burnt live flesh, but I think it would well repay a doctor to do so.

Taking actual cases :—

"C." was working on a high-tension switchboard and received a 2,000-volt alternating shock. The man was killed. I myself saw the body, and noticed that there was only a slight burn on the left hand, no other mark being found on the body. It was therefore impossible to say how the man really received the shock. I am sure the burn was only slight, and as I have had considerable experience of electrical burns at various voltages (both alternating and direct), I think I am in a position to judge as to their severity.

"F." received a 2,000-volt alternating shock from hand to hand. Death occurred. The engineer-on-watch at the time told me that only slight burns were on each hand.

In the case mentioned of a man killed on an arc circuit, only a slight redness was seen on his hand. Of course, this may not always be the case, as it is quite possible that the victim in his struggles to escape may reduce the contact and therefore cause severe burning after he had received sufficient current to kill him. In previous cases I have mentioned where the victim recovered, severe burning took place, and I shall mention more later on.

I know I am laying myself open to severe criticism in bringing forward this theory, as the majority of electrical engineers, and also the doctors, believe that severe burning means a severe shock, and to illustrate this I cannot do better than again quote Dr. Oliver in Allbutt's *System of Medicine*, page 857, where he says: "If the skin at the time of contact was moist, so much more the burning. If a

current sufficient to produce this severe local burning pass through the body, fatal results are more probable." My own opinion is, however, from reasons stated above, that moistness of the skin reduces the chance of burning as it ensures better contact, and if no burning takes place, efforts to help the victim should be redoubled if it is thought that he has received a shock, as it is quite possible that, owing to this misapprehension, he may be thought to be ill from some other cause.

I should like to say a good deal more on this question, but as the time is short will proceed to the next point.

6. *Can a person receive a fatal shock without giving the cry, and also can he speak after receiving a fatal shock?*

It may be of interest to attempt to describe the cry, and as I have heard it three times, and have discussed this matter with others who have heard it, I think it can be accepted that this cry is best described as a rapid drawing in of the breath, followed by a half sigh, half shriek. In each of at least a dozen cases of more or less severe shocks that have been reported to me the victim gave the cry, but in the case in which I personally saw the victim three witnesses were sure that he did not give the cry.

With respect to the question as to whether a person can speak after he has received a fatal shock, I may say that I have always thought this impossible; but in the above case the victim was asked if he was hurt, and he said, "I am all right," and yet directly afterwards dropped down dead. Of course one may ask, did he really die from an electric shock? but as a post mortem was made, and the doctor satisfied himself that all the organs were healthy, I think there can be no doubt about it.

I think, therefore, that further information is most urgently required; but at present one can only say that a man need not give the cry, and that it is possible for him to speak after a fatal shock has been received.

7. *Is an alternating or a direct-current shock more likely to prove fatal?*

This question may be looked at from two points of view:—

First: If a man is killed by an alternating shock, would not a direct-current shock prove equally fatal, provided the conditions in each case were exactly the same?

Secondly: Is there anything in the actual working conditions which makes one supply more dangerous than the other?

Considering this from the first point of view, the question immediately occurs: Do both kinds of shock affect the body in the same manner from a medical standpoint? Of course I am not in a position to judge, but as a direct-current causes electrolytic action, and an alternating-current does not, it seems that more must take place with direct-current than with alternating-current. My attention has been called to the fact that under certain conditions alternating-currents will cause electrolytic action. Any information on this point would therefore be valuable.

It is also open to discussion whether, disregarding electrolytic action, the two act the same, as the alternating from its nature must have a spasmodic effect, whilst a direct-current seems to paralyse at once. From my own experience of shocks, I am certain that the after-effect of a direct-current is worse than that of an alternating current.

When looking at the matter, however, from an electrician's point of view, I can see a great difference, as there is no doubt that if contact is made with metal of such a shape that it cannot be gripped, and the current passes from hand to hand, the direct-current seems to knock the victim down, whilst an alternating-current seems to draw him closer and to tie his body as far as possible into a knot. On the other hand, if he can grip the metal, the direct-current seems to hold him tighter than does the alternating-current. Of course I am only judging from what I have seen and felt myself.

Another influence which I believe plays an important part is the different action which the two currents have in breaking down a fault. For instance, if the insulation is faulty when current once commences to pass, the direct-current will break a fault down more quickly than will an alternating-current. No doubt this has some effect when a shock is received, as most probably the direct-current would reach its maximum before the alternating-current, and,

therefore, if a person is only in circuit for a short time, the direct-current would have the greatest effect. On the other hand, more burning will take place with direct-current than with alternating-current, and as I have pointed out before, this is most probably a protection.

My own opinion is that both currents will kill a man equally well, provided that the conditions are the same, and that death ensues from an electric shock.

Although not strictly included in this paper, I should like to draw attention to the fact that an arc is more easily started with direct-current than with alternating-current, and that when once started it is more easily maintained. This is evident from the fact that a fuse which is quite safe on alternating-current is utterly useless on direct-current circuits. From the above cause it is possible for a man to be severely burnt on continuous-current, and therefore all cases of exceptionally severe burning, if they occur on a low-tension supply, should be thoroughly investigated to prove whether death occurred from a shock due to burns or to an electric shock.

The conclusion I come to is, that if death occurs from an electric shock, both are equally dangerous; but if death occurs from burns, the continuous-current is more dangerous. To make myself thoroughly clear, I should also like to say that although burns are a protection against electric shocks, yet if carried to extremes they may themselves cause death due to shock.

In considering the second question, it must be remembered that although the majority of deaths from electric shocks occur with alternating-currents, yet the potential usually worked at with alternating- is higher than that with direct-current, and therefore the conditions required to cause death have to be more favourable with direct-current than with alternating-current.

Taking the actual voltage required to cause death, independent of nature of supply, I should say:—

At below 600 volts the conditions must be abnormally favourable.

At below 1,000 volts the conditions must be favourable.

At above 1,000 volts the higher the pressure the more

easy it is to get the conditions necessary to cause death.

In comparing the relative dangers of the two sources of supply, it must be remembered that even with the same voltage and conditions, it is quite possible to meet with an accident from quite different causes due to the kind of supply. For instance, with an alternating supply where the outer is earthed, nine times out of ten a shock is received not by getting into the circuit proper, but by touching some metal which has become charged owing to its not being properly earthed, or to not realising that any earthed metal is practically the outer. I think, however, that accidents from this cause will be fewer in the future now that the precautions required are thoroughly understood, and, more important still, that we are able to obtain trained men.

On the other hand, with direct-current, most accidents occur due to an earth on circuit causing a man to receive a shock when he accidentally earths the circuit in another place through himself.

The conclusion I come to is that there is nothing more dangerous in one system than in another. It is purely a question of voltage and of the conditions being favourable, and it must be remarked that as many conditions have to be favourable, it is really so difficult to get killed, even with a high voltage, that practically, with our present knowledge, the chance of this occurring is no greater than in numerous other occupations where a person is likely to meet with an accident.

8. *Cannot the Medical Profession give us a more certain method of ascertaining whether a man is dead or not?*

In the *Electrical Review* Rules, which I consider most excellent and indeed invaluable, it is recommended to ascertain if the sphincter muscle is relaxed; but as this is for obvious reasons objectionable, and also to a non-medical man most difficult to judge, I ask the doctors if they can tell us some better method. If they only knew what one feels when, after doing all one knows to restore a fellow-worker to

consciousness, the question arises, Am I simply manipulating a dead body? I feel sure they would do all they could to tell us how to arrive at a definite conclusion.

9. *Cannot something more be done to help those who receive a shock?*

In discussing this question, the first thing which strikes me is how utterly we engineers are in the dark as to what really happens to a human body when death is caused by electricity.

Of course, death is a stoppage of the functions of the body; and looked at from an engineering point of view, I think the organs of the body can be best described as follows, namely, the lungs as the boiler, the heart as a pump, and the nervous system as mains to transmit signals from the controlling power (the brain) to the various machinery operated, and the arteries and veins as feed-pipes. Now, to my mind, what we want to know is, what breaks down when a shock is received? Are the lungs so damaged that they are useless for further work? or is the pump, the heart, broken in any way that it cannot work,—for instance, are the valves ruptured or the arteries, viz. the feed-pipes, broken? or is the blood, the feed water, so decomposed that it precipitates and chokes the pipes? or cannot signals be sent from the brain, owing to the nerves being paralysed? or what happens?

Looked at from this point of view, the first thing which requires clearing up is, are the conditions found inside the body different when death has been caused by electricity to those found when it occurs from shock from fright, excitement, burns, amputation of a limb, etc. Of course I, personally, cannot say, but from medical evidence which I have read it appears as if the only thing which is unusual is that the blood appears different at post mortem; but I believe this is open to discussion.

I, myself, think, however, that when it is considered, as I have pointed out previously, that an idiot does not seem to feel a shock so severely as an ordinary person, and also that during sleep less is felt, the truth will probably be found to be that electricity acts like an anæsthetic, such as chloroform. My reasons for believing this are also due to the fact that in two cases of an electric shock where death would have

been expected, the men recovered, in my opinion, from the head being lowered, thus flushing the brain with blood, which is exactly what the doctors do when they want to revive a patient who has collapsed when under chloroform.

The cases referred to are as follows :—

"B." received a 2,000-volt shock from hand to hand, but was not badly burnt. He was insensible : we could not feel his heart beating, and his breath did not cloud a mirror ; his eyes were turned so that we could see only the white of the eyes, his jaw was dropped, and thus seeing the man I could have been certain that he was dead. This man gave the cry, and an engine-driver who picked him up stood him on his head, and thumped his chest, his reason being, as he put it, to start the blood flowing, and, as the heart is a pump, to free the valves if they were stuck. After forty-five minutes' artificial respiration this man recovered.

"T." received a 2,000-volt shock from hand to hand. He was standing on a pair of steps. As no one was present I cannot say if he gave the cry, but at any rate he fell head first off the steps about four feet to the floor. He came round without assistance in about twenty-five minutes. It is only fair to say that his hands were badly burnt.

The question, therefore, which I wish to ask the medical profession is, should we adopt the same treatment as is used for collapse from chloroform, and when a man receives a shock should we, before applying artificial respiration, hold the body for a few seconds head downwards at an angle of 45 deg., thus flushing the brain and stimulating its action ? I bring this theory forward with the greatest diffidence, but as I have actual cases to bear me out and also other evidence which points the same way, I think that considering its vital importance to humanity, I am justified in doing so in the hope of its being investigated by the medical profession ; but until this has been done, no one realises better than myself that my evidence cannot be considered as conclusive.

In conclusion, I can only say that I am fully aware of the shortcomings of this paper, but it is a real attempt possibly to save a human life by thus endeavouring to get members to give information on this question which so immediately concerns us as electrical engineers.

ELECTRIC SHOCKS AT FIVE HUNDRED VOLTS.

By ALEXANDER PELHAM TROTTER, Member.

A good deal of misapprehension exists as to the circumstances under which shocks at 500 volts may be felt, or the conditions which may lead to serious consequences. The electric pressure of 500 volts has become well established as the standard for electric traction, but apparatus designed for this pressure can be arranged to take another 100 or 150 volts without appreciable alteration. Considerations of commercial standardisation seem to set the limit for working at about 600 volts; and it is fortunate, from the point of view of safety, that no further extension of pressure under ordinary conditions is likely to be needed.

Since in a few cases shocks at 500 volts have been fatal, newspapers have not hesitated to argue from the particular to the general, and have assumed that all such shocks involve serious injury, if not death. For once, they are in good company: the technical press and eminent practical electric traction engineers seem to have a horror of 500 volts. Such horror has its wholesome side, but ignorance brought face to face with imaginary horror may result in panic. Modern journalistic sensationalism has made the most of the accident which occurred in Liverpool, in February, 1901, and such was the scare that months afterwards, when a harmless necessary trolley-wire fell on a tramcar, passengers, not only jumping to the conclusion that they were threatened with a hideous death, jumped to the ground and sustained serious injuries. Irresponsible correspondents have suggested in the newspapers that to fall on the electric rails of the Central London Railway is to be grilled alive; they knew no better. But when, during the inspection of the last extension of the City and South London Railway, I stood on the rails in wetted boots, and sat on the live conductor and slapped the running rails with my bare hands, engineers, electricians, railway employés and others who ought to know better, were surprised, and spoiled the effect of my demonstration by suggesting that I was peculiarly insusceptible to shocks.

A pressure of 300 volts was used at first for electric traction, but when afterwards it was taken up and developed

by Americans, they settled by *experimenta in corporibus vilibus*, that a pressure of 500 was high enough for economy and not too high for safety. The chief object of this paper is to record a few experiments and to discuss the conditions under which shocks at 500 volts are devoid of danger.

The subject may be divided into three parts: (1) The physiological and electrical conditions; (2) the dangers connected with trolley-wires; (3) the dangers of third rails of electric railways.

Physiological and Electrical.—In dealing with the first part, I need but barely allude to physiological matters, but will refer first to the current, then to resistances, and lastly to pressure. The sensation may be a prick, a pleasant tingle, a hot burning, or a convulsive shock. The sensation does not depend directly on the actual current, but on the current density. With four or five square inches (30 square centimetres) of contact between dry metal and bare skin (for example, grasping a trolley-wire), a steady continuous current of 1 or 2 milliamperes is hardly perceptible.[1] From 3 to 8 are easily supportable, above 10 milliamperes is painful, and above 35 almost unendurable. A larger current than 20 milliamperes is seldom used for medical applications. Every electrical engineer is familiar with the sharp pricking shock given by a fine wire. In that case the current density is very high, but the current is so small that little else than the tactile nerve endings in the skin are stimulated. With larger currents and more surface, muscular contractions are added to the tactile sensations, especially if the current is at all unsteady. The electrical phenomena of nerve and muscle have been studied by physiologists, they are rather complicated, and do not concern the general purpose of this paper.

Alternating currents seem to be about four or five times

[1] If this paper be read, as I hope it may, by others than electricians, it may be well to explain that one ampere of current passes through a resistance of one ohm when the electrical pressure is one volt. One milliampere, or one thousandth of an ampere, passes through a resistance of one thousand ohms when the pressure is one volt, and one milliampere passes when the resistance is one hundred thousand ohms and the pressure one hundred volts, and so on in proportion.

Volts.	Milliamperes.	Ohms.
1	1,000	1
1	1	1,000
100	1	100,000
500	5	100,000

more painful, but the sensation is of a different character. I have no knowledge of the relative danger of alternating and of continuous currents, and no further reference will be made to alternate currents in this paper.

It is difficult to make any exact determination of the relation between current density and sensation. More than about 14 milliamperes of steady continuous current at the finger tip, making a poor contact of about $\frac{1}{6}$ of a square inch (1 square centimetre) is unendurable, but 35 milliamperes from boot to boot, nearly the whole of the soles of the feet being in contact, is much less painful. Under prolonged shock the current increases, owing to a fall of resistance, but that does not concern accidental shocks.

Passing now to resistances, the resistance from finger tip to finger tip on dry metal and under 100 volts, is about 20,000 ohms. It varies a little with the volts, decreasing at higher pressures. Two coins nipped in the terminals of an Evershed Ohmmeter serve very well for electrodes. This finger-tip resistance is of considerable importance in connection with accidental light contacts at high pressures. The resistance is almost all at the skin. The thin skin on the inside of the wrist is much more sensitive than that of the palm of the hand. The difference between the resistance from finger to finger of one hand and between one finger of each hand is inappreciable. The resistance from hand to hand when grasping two pieces of dry trolley wire is about 5,000 ohms; different individuals vary a good deal, probably owing to the dryness of the skin; I have found it as high as 14,000. The resistance between the body and the earth or an iron rail through the sole of the foot, stocking, and boot, is of considerable importance in connection with electric railways. I find that the resistance from boot to boot, the boots being dry and without nails, varies from 45,000 to more than 200,000 ohms. The lowest of measurements on 25 different persons made with 500 volts, gave 25,000 ohms. Boots worn into holes and wetted by walking on wet pavement, gave only 13,000. The values for resistance of the human body given in medical works are of little use for the present purpose, for care is taken as a rule to facilitate the passage of the current. "Under conditions of medical practice, and using moistened

electrodes, the resistance of the body, when the skin is well wetted with warm water, is about two or three thousand ohms, that is to say, an electromotive force of twelve volts (eight Leclanché cells) will pass a current of four to six milliamperes." ("Medical Electricity," Lewis Jones, p. 194.) Most of the measurements of resistance which I have given were made with 100 to 500 volts and are calculated from the milliamperes which passed. Taking the information which I have already given about the effect produced by various currents, it follows that the mere touching of dry metal at 100 volts, finger to finger, gives hardly any sensation, but with a larger contact a shock is felt. At 200 volts a light touch gives an unpleasant prick, but the current through a firm contact is about 12 to 18 milliamperes, which most people can bear without considerable pain, especially if the contact be gradually made and broken. There is no after effect; the sensation is very similar to that of heat.

To grasp, with bare hands, two pieces of metal at 500 volts would give a very painful shock, but a light and quick touch is no worse than the shock from a half-pint Leyden jar, an experience more familiar to schoolboys than to engineers. A 500-volt shock may be described as worse than touching a kettle of boiling water, not so bad as touching a red-hot poker, about the same as touching a soldering iron at working heat, or as when an inexperienced blacksmith's boy picks up a black-hot horseshoe. These shocks are common incidents in the daily work of a careless linesman; nearly all those who are practically engaged in electric traction work receive more shocks than they like, but they agree that *they might reduce the number by taking more care.* This is an important measure of the severity of such shocks, and perhaps the only one which will be appreciated by those members of the public who do not care to try for themselves. In such brief shocks the muscular sensations probably mask the contact sensations, but a bad 500-volt shock burns the skin.

Cases of fatal accident from 500 volts are so rare that the conditions can only be guessed at. If the skin resistance be reduced by moisture, especially if salt or chemicals be present, and if the contact be large and prolonged, 100 volts may be fatal. While repairing an arc lamp in a steam washing factory at Bradford, in 1899, a man is said to have

been killed by a shock at 225 volts; a fatal accident occurred in Germany with about 300 volts, but a man may be choked by a crust of bread under exceptional conditions. The death of a man by blood-poisoning arising from a burn caused by a short circuit on the Central London Railway in December, 1900, does not concern us; a death occurred on the Metropolitan Railway in Paris, when a plate-layer fell and remained fallen on the third rail of 500 volts, but the case to which so much attention has been drawn, and which has caused such a scare, is the accident in Pembroke Place, Liverpool. Instead of the present system of well earthed guard wires, an attempt was made to keep fallen telegraph wires from touching the trolley wire, and the attempt was unsuccessful. Nearly fifty wires fell in a tangle across the street, and lay on the trolley wire, which did not break. The passers-by in the street upon whom they fell escaped with a few shocks. It was dark and snowing, and a salted slush lay on the street. Two men walked blindly into the wires and were entangled, and struggling, became entangled the more. The current was not cut off for nearly half an hour. Here was a lamentable combination of seven circumstances. (1) The unusual conditions of weather, the snow freezing to the wires as it fell. (2) Failure of the wood strip (which is still extensively used on the Continent) to act as a guard. (3) The large number of wires, the long span (375 feet), and the tangle in which they fell. (4) The salt slush of snow in the street. (5) The darkness and invisibility of the wires. (6) Failure of the Police telephone signal service. (7) The delay of 25 or 30 minutes before the current was cut off. If any one of these seven causes had been absent it is probable that the fatal results would not have occurred. It is practically impossible that such an accident can occur again in Liverpool, for the telephone wires which crossed the tramways have been either diverted, placed underground, or cabled, at a great expense to the Corporation, and a considerable number of the Postal Telegraph wires have been satisfactorily altered. I am tempted to digress into the question of guard wiring, but this paper must be confined to shocks, and I hope that the discussion will be similarly restricted.

Dangers connected with Trolley Wires.—Neither the man in the street, nor a man on a car, runs any risk of

taking 500 volts skin to metal. On several occasions during inspections of tramways, when a trolley wire has been within reach from the top of a car, I have grasped it with both hands, and with more or less difficulty I have persuaded others to do the same. In each case the weather was fine, the car dry, and no shock, not even the least sensation was perceptible. To show that there was no trick I have grasped the hand-rail and flicked the trolley wire with a finger; the shock is trifling. It follows, therefore, that if a live trolley wire fall on a crowded car, although it may give alarming flashes when it touches a hand-rail, or tramway rail, the chances of a shock on a fairly dry day are nothing compared to the obvious mechanical injuries which might be occasioned. Trolley wires do fall, and trolley wires are very properly excluded from the leading cities of the world—London, Paris, Vienna, New York, Buda Pest, etc., but as yet the damage done by the falls has not been electrical. A trolley-wire is an obvious thing; it sometimes springs back in large coils, but it generally falls and lies still or hangs, and is regarded with a prudent solicitude which this paper is not intended to remove. But on a dry or frosty day any one with tolerably good boots may fearlessly touch the live end even if he stand on the rail. I would not publish this statement had I not tried the experiment on some dozen persons, the majority being women and children. My son, 7½ years old, stood on a rail and played with wires, there being 500 volts between rail and wires. The current was less than ¼ milliampere, and he felt nothing. His boots were new. A fallen telephone wire is not so obvious; it does not stop the traffic; it is apt to writhe and to coil round a person; should he fall on the rails the short circuit might severely burn him. With wet boots and ground the conditions are different. Standing on damp granite setts in rather damp boots, and grasping a trolley-wire, I found the current was 15 milliamperes, the sensation was by no means unendurable; brief touches gave sharp pricks. Standing on a rail increased the current to 20 milliamperes. With old boots worn into holes, and after walking a couple of miles on wet pavement, standing on a rail and grasping a trolley-wire gave 35 milliamperes. I took this for several seconds, and I should be sorry to take more. I broke contact cautiously by raising the boot on

one edge. There was no after effect; the sensation was merely that of heat, as though the trolley-wire were hot. Spilling half a bucket full of water on the ground increased the shock intolerably. I am inclined to attribute this to the better contact between boot and earth rather then to decreased resistance of the earth (in this case granite setts). Three others tried the experiments with me, and as far as we are able to compare experiences I am satisfied that I am not relatively insusceptible to shocks.

Besides the fall of trolley-wires, either on a car or in the street, there are roundabout and unlikely ways in which shocks may be conveyed to unsuspecting persons, for example, a linesman on a ladder, and somehow making a good earth, holding a wire while its broken end or a careless sag touches a trolley-wire; but the discussion of such accidents belongs to the subject of guard-wires.

Dangers connected with Third Rails.—The first time I stepped on the live rail of a third-rail railway, I clutched the engineer, lest my legs should give way under the shock; but I felt nothing. I went to where some water stood half an inch deep on a cement floor, and "marked time" for two and a half minutes. With caution, I stepped on the live rail and then on one of the running rails, felt nothing, stooped down and touched the running rail while standing with both feet on the running rail. I felt a slight tingle, which my subsequent experiments lead me to think was produced by a current of about 6 milliamperes. To sit on the live rail without touching the running rails was easy, and I cautiously flicked the running rail, then touched it, and then laid my hands flat on it without the slightest sensation. In the light of the figures I have given, this is not at all surprising, and I have invited several others to try the experiment, with the same negative result. Of course the result depends on the dryness of the clothes. The resistance of dry cloth is very high. After walking in the wet for about an hour with sound but not thick shoes, I stepped on 500 volt rails and felt nothing, but on touching with the finger I received a smart shock, perhaps 30 milliamperes. I have already stated that with old worn-out wet boots the resistance was only 13,000 ohms. This was found with only 400 volts. Standing on rails in my laboratory, the rails being connected to the outers of the

Westminster Company, I could just support the current of about 30 milliamperes. The sensation was almost precisely like standing on hot steam-pipes. It was easy to turn it on gradually by beginning and ending with the edge of the sole. The shock would of course be very alarming to any one who was not expecting it. There was no perceptible after effect. Ordinary nails in the heels of boots make no difference, but hob-nails give uncertain pricking stings which are rather painful, but under no circumstances need they be sustained.

Until I tried these experiments, I must confess that I did not enjoy the walks which I have sometimes taken in "tube" railways during inspections by the light of oil lanterns, but now, with dry boots, I take no care whatever. It is very desirable that the live rails of third-rail railways should be guarded by planks to prevent short circuits by tools, etc., and to make it less easy for a person falling on the rails to make contact with bare skin. While experience has shown that a person so falling may receive a serious and even fatal shock, this can only occur if he make contact with both a live rail and a running rail with bare skin, or thoroughly wetted clothes, and if he lie there for a time. As to the length of this time we know nothing, but so long as the fall has not injured the person, so that he cannot rise, it is very improbable that the shock would be maintained. A platelayer in the open yard of the Waterloo and City Railway, once accidentally sat on the third rail, and made the circuit through his feet on wet ground; he shouted, and was pulled off by his mates: the contraction of the muscles prevented him from rising. He could probably have rolled over, and so released himself. He was back at work again in a few minutes.

Numerous accidents to horses show conclusively that these animals are peculiarly susceptible to electric shocks. Electrical conditions under which a human being would receive an unpleasant shock of 10 to 15 milliamperes cause instant death to a horse, and it appears that horses are terrified under conditions where a human being would feel no shock. But it must not be concluded that a given current produces more effect on a horse than on a man. A horse makes excellent contact with its shoes, and these are well connected by nails to its body. It is probable that the

resistance is very small, and the current very large; but even making this allowance, the horse appears to be more susceptible.

Conclusion.

The dangers of electric shocks at 500 volts have been much misunderstood, greatly exaggerated, and little investigated. The pressure of 500 volts has been deliberately chosen by electrical engineers because it is not dangerous under ordinary conditions. The conditions under which serious shocks *are not produced* by 500 volts are discussed in the paper, and it is safe to assume that all shocks more serious than those which are recorded, are dangerous.

Dry wood and dry boots without large nails offer so great resistance to electric current, that it is perfectly safe to touch a trolley-wire while standing on a dry tram-car, or even while standing on the ground, or on the rails. Wet weather makes a considerable difference, but boots must be very wet to allow enough current to pass to produce a severe shock.

Men engaged in electric traction work receive many slight electric shocks at 500 volts, and they might avoid most of them by taking more care. Dry clothing offers so great a resistance that no shock can be transmitted through it. The peculiar conditions under which shocks at 500 volts have caused death are discussed, and are shown to be very exceptional.

Experiments have been made on some thirty persons, including twelve women and six children, and it is proposed to make other experiments.

With sound dry boots hardly anybody can feel a shock when standing on the live rail of an electric railway with one foot, and a running rail with the other. With damp or wet boots a shock is felt, but neither the sensation nor the degree of wetness of the boots can be measured accurately. It is not possible to receive a shock by sitting or lying on a live rail so long as the clothes are dry and continuous, that is to say, so long as the live metal is not touched by the bare skin.

After the reading of the paper, the author made some demonstrations. The following table was displayed on the wall, in order that

the indications of the milliampere-meter might be converted into resistance in ohms. :—

RESISTANCES AT 500 VOLTS.

Milliamperes.			Ohms.
1.	...	...	500,000
2.	...	...	250,000
3.	...	...	166,666
4.	...	...	125,000
5.	...	...	100,000
10.	...	...	50,000
15.	...	...	33,333
20.	...	...	25,000
25.	...	...	20,000
30.	...	...	16,666
35.	...	...	14,286

The current was supplied by secondary batteries kindly lent by Messrs. Sutherland and Marcusson. In order to show that this battery was a suitable source of current for the demonstration, a bank of 25 lamps of 5 candle-power each was provided by the General Electric Company. These lamps were wired five parallel and five in series, and took about one ampere. The battery was capable of lighting them brightly, and the lamps were turned on for a short time before and after the demonstration.

Five lamps of 3 candle-power were arranged in series on the 500 volts, and between each pair of them a metal plate about an inch in diameter was fixed and connected to the circuit. Touching two adjacent plates with the finger-tips, the author received a current of about one and a half milliamperes. This current was shown on a large station ammeter which had been kindly provided by Messrs. Crompton & Co., who had specially wound and calibrated it in milliamperes for the occasion. The author showed that by placing his fingers flat on the plates the current was increased to about 4 milliamperes, owing to the increased surface and diminished resistance. He then touched two plates (having 100 volts between them) with two fingers of one hand. The current was practically the same as when one finger of each hand was used, thus proving that the resistance of his two arms and chest was negligible compared with the resistance of the skin of the fingers. He then held two lengths of trolley wire lightly, one in each hand, and made contact with 100 volts. The current was about 6 milliamperes; then gradually bringing more and more skin into contact with the trolley wires, until they were grasped firmly in each hand, the current gradually rose to about 16 milliamperes. He relaxed his grasp gradually, thus avoiding the shock which occurs both on making and on breaking a considerable current. He next touched two plates differing by 200 volts with his finger-tips, and received about 14 milliamperes. This was more painful than the larger current at 100 volts, on account of the small surface and high current density. He gradually increased the current by increasing

the surface of skin in contact until he took about 20 milliamperes, which gave painful sensations, but not so severe as those often sustained for amusement when shocks are taken for a penny at a fair.

Two lengths of railway rails, about 18 inches long, were laid on the floor, and were connected to the battery. Standing on one of these, in thin dry evening shoes, the author touched with his finger a metal plate differing from the rail by 100 volts. The ammeter did not move. Then passing his finger from one plate to the next, he touched the successive plates until he reached the one differing from the rail by 500 volts. The ammeter hardly moved. Then grasping a length of trolley wire he touched the 500-volt plate, and the ammeter showed about one milliampere, but no sensation was felt. The author explained that as he stood he was, electrically, in exactly the same conditions as though he stood in a street on a tramway rail, in his thinnest shoes, and grasped a live trolley wire fallen in the street. He then changed his shoes, putting on ordinary walking shoes which had been worn all day, and which were tolerably damp. The current under these conditions (standing on a rail and touching the 500-volt contact) was about 10 milliamperes. Standing first on one foot and then on the other, one foot being clad in a silk sock and the other in thin merino. the former showed a rather lower resistance; but this might have been due to a difference in the dampness of the shoe.

A length of about 5 ft. 6 in. of the conductor rail and of the two running rails of the Central London Railway, had been kindly provided by that company. These were mounted on trestles. Standing near the end of these rails, the author laid a piece of cloth on the conductor rail, and touched one of the running rails with the finger of one hand. He then lightly touched the cloth, with no result; he touched it more firmly, and finally laid his hand flat on it. The cloth was enough to prevent any perceptible current to pass at 500 volts. Two folds of cambric handkerchief, similarly, were enough to insulate, and even one fold, with moderate pressure, behaved in the same way. With the full palm of the hand pressed down, there were slight pricks, but not enough to show on the ammeter. He then dipped the cloth in water, wrung it out, and wiped off the surface moisture. First touching it lightly, and afterwards with considerable pressure, no sensation or measurable current (say one quarter of a milliampere) passed. Repeating the experiment after a second damping he received smart pricks, and he explained that if time permitted, a state of dampness could be obtained which, under pressure of the hand, would give a current of 10 to 30 milliamperes.

He stated that the experiment which he had shown with dry cloth was convincing, and was sufficient for all scientific men and engineers, but he proposed to repeat the experiment in another way which would appeal to a wider audience. He then sat on one of the running rails, and (though knowing the result) cautiously flicked the conductor rail with his finger, then touched it lightly, then firmly, and finally laid his hands flat on it. There was no sensation or measurable current. He then lay down across the three rails, and rolled over from end to end

of them and back again. While lying on the rails he laid his hands first on a running rail, and then laid them on the conductor rail, with no sensation of shock. The author observed that such a demonstration was open to being called a clap-trap performance, but he justified it as an undeniable proof of one of the many conditions under which no shock is felt at 500 volts.

The author concluded by touching one of the rails and flicking the other with his finger. The effect is rather painful on account of the high current density, but the current was too brief to show on the ammeter.

The PRESIDENT: We are greatly indebted to the authors of these papers for having produced these most interesting details: details which, I think, will be of influence in enabling the medical profession and other scientists to arrive at some solution of the important question which has given rise to the papers. I should like to thank Mr. Trotter especially for the demonstration he has given us, because I think it must tend in a very effectual manner to remove from the minds of many people the dread they have of the consequences that attend contact with the trolley wires and railway metals of electrical systems. He has, I think, quite exemplified the fact that only under exceptional circumstances can shocks of a serious character be incurred. I should like, as Mr. Cunynghame is here, to ask him if he will open the discussion on these papers. The President.

Mr. H. H. CUNYNGHAME: Possibly the reason the President has asked me to say a few words is that I am connected with the Home Office in the administration of the Factory Acts. Upon that point I do not propose to say anything, except this: when I was a member of the Royal Commission on Railway Accidents, I remember putting this question two or three times to the greatest engineers who appeared before us. I asked them, "Will you be kind enough to tell me whether in the whole course of your experiences, you know, or are able to ascertain, one case in which the Factory Laws have been really a substantial drawback to trade? In a few instances, of course, they have caused a little inconvenience, but are you able to name one serious instance?" and in every case, after having days to think about it, it was admitted that no case could be found. Looking to the severity of the Acts, there can be no doubt that if they were not wisely administered they could be made a burden, but I am perfectly certain, from what I have heard the Secretary of State to the Home Department say on platforms and at deputations and to us, that there is not the slightest intention of making these Factory Acts anything but a means of securing safety to the workmen. I do not believe that trade need be under any anxiety about it. Mr. Cunynghame.

From experiments that I remember making some years ago on the way in which people could stand shocks from small magneto-machines, I could quite believe that horses are much more susceptible to it than men, chiefly for the reason that women are distinctly less susceptible to it than men, as far as I could ascertain. There seems to be little doubt that the nervous organisation of women

Mr. Cunyng- hame. —I speak with the greatest deference in the presence of medical gentlemen—is not so highly developed as that of men, and they can take a considerably greater shock than men can. I have no doubt that creatures like horses, and, possibly, dogs, that have an extremely high nervous organisation, would feel it more than we do. At all events, in all the experiments that have been made with a view to testing the nervous susceptibility of the skin, men seem to have a greater capacity for feeling a nervous tactile sensation than women. There is only one other point I should like to hear some of the doctors upon. I believe it has been a moot point amongst medical men how far what may be called nervous shock, entirely without pain, can affect the system. Some experiments were tried last year—vivisection experiments—by putting rabbits and creatures under complete chloroform, giving them some operation which must have been terribly painful had they been conscious, and then observing the effect of that unfelt nervous shock upon the system. It would be very curious to know how far the pain felt in an electrical discharge is a measure of the injury it may do. With regard to the experiments on ohmic resistance, I was rather surprised at Mr. Aspinall's figures of 60,000 and 100,000 ohms. I suppose he must only mean just touching the conductor with the point of the finger, because all the experiments I have ever seen tried, where one grasped a tolerably large metallic object, seemed to give a resistance much more like 20,000 ohms, and much less than those in the case of those people who have damp hands.

Sir B. Gurdon. Sir BRAMPTON GURDON: In reply to your invitation to speak, I may say that I can only thank the authors for the exceedingly instructive papers which they have read to us. Unfortunately, though perhaps years ago I knew a little about electricity, that science marches so fast that those who have not time to study it and keep it up fall entirely behindhand, and therefore I think I am extremely fortunate in having been able to come here on a night when the subject is such that it may be interesting even to people who are as ignorant as myself of that science in which you are experts. I wish to say, not having been here for some time and having belonged to the Society almost from its beginning, that I am much pleased to see the growth of the Institution, and the splendid gathering we have here to-night.

The President. The PRESIDENT: In view of Mr. Trotter's further experiments I am afraid we must adjourn the meeting now. I am very sorry that such is the case, but I am sure there are a great many gentlemen present who will be very glad indeed to contribute something to the discussion on a future occasion. I hope it will be convenient for them to attend the next meeting, when we shall probably devote the whole evening to the consideration of the subject.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

Percy Nicholas Hooper. | George F. Mansbridge.
William Edward Thrift.

Associate Members.

Arthur Harold Abbott.
A. Cathcart Coubrough.
Robert Niven Fulton.
Harold Hale.
Charles Baird Handyside.
Edgar Hesketh.
Robert Frederick Looser.
Randall Beresford Slacke.
Edward Threlfall Vickers.
William Bradley Woodhouse.

Associates.

William Bannister.
Leonard Breach.
Charles Henry K. Chamen.
John Edgar Edmundson.
Wycliffe G. Everingham.
Thomas Ferguson.
David Furniss.
Ralph Edgar Gott.
William Turnbull Gray.
Harry Green.
James John W. Grigg.
John Richard W. Linton.
James Lord.
John Ernest Newman.
Bernard J. Pargeter.
John Ernest Raworth.
John David Richards.
Percy Edward Ridley.
Herbert William Stovold.
Ernest J. Taylor.
Alfred Walker.

Students.

Charles Antony Ablett.
Ernest Ambrose.
John Arnold.
Douglas Stephenson Baddeley.
Mul Chand Badhwar.
Herbert F. Bayley.
Alfred William Beuttell.
Charles Roxberry Bland.
Charles Bounett.
Bernard E. Bumpus.
Reginald Arthur Bush.
Michael Chapman.
Carleton Philips Cobb.
Bernard G. Drummond.
Gregory Hugh Walter Gaspar.
William Delano Halfhead.
Thomas Crespin Harrison.
Cecil D'Aguilar Jackson.
Henry Francis Jay.
David Kennedy.
Cyril Lawton.
Stanley Walter Lough.
John Ernest M. McGregor.
Edwin Lewis Monk.
Douglas Noel Milestone.
Edgar Arthur A. Parsons.
Hubert Charles N. Prance.
Arthur Lionel Rawlings.
Leonard Roseveare.
Arthur N. Rufford-Sharpe.
Mahmoud Samy.
R. Melville Smith.
Albert John Geo. Swinney.
Oliver Charles Thompson.
James Tyrrell.
Henry F. Vickery.
Thomas Harry Vitty.
David Christian Wardlaw.
Hubert Hope Wardlaw.
Arthur Hamilton Wilson.

The Three Hundred and Seventy-fourth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 13th, 1902—Mr. R. K. GRAY, Vice-president, in the Chair.

The minutes of the Ordinary General Meeting held on February 22nd, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Alfred Charles Holtby.

From the class of Associates to that of Associate Members—

Arthur Bentley.
John Dennis Coales, B.Sc.
Richard T. Durran.
Edward Cecil H. T. Lugard.
John Hayes McDowell.
Herbert St. Hill Mawdsley.
W. M. Nelson.

From the class of Students to that of Associates—

A. F. T. Atchison.
William Walter Bradfield.
Charles Wilfred Hacking.
Philip Hunter-Browne.
Charles William Lund.
Percy Godfrey Pettifor.
Robinett Scruby.
George Stevenson.
William Thomas Trusler.

Messrs. E. J. Howell and W. P. Whitehead were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from the Maschinenfabrik, Oerlikon, and Mr. W. Perren Maycock (member); to the *Building Fund* from Messrs. R. H Burnham, A. D. Constable, H. J. Garnett, H. J. Gridley, T. E. Ingoldby, and F. Langley; and to the *Benevolent Fund* from Mr. C. P. Cobb, to whom the thanks of the meeting were duly accorded.

The CHAIRMAN: You will have noticed that your President is not here to-night. The reason of his absence is that he is representing the Institution at the Jubilee of the Owens College, Manchester. One of

his duties at the celebration is to present the following address which has been drawn up by the Council :—

"TO THE OWENS COLLEGE, MANCHESTER.

"The Institution of Electrical Engineers is gratified at being honoured with an invitation to assist in the Jubilee celebrations of the Owens College, and, in accepting that invitation, gladly avails itself of the opportunity to convey the hearty congratulations of the Institution on the valuable work accomplished by the College in the cause of education, and particularly in the promotion of the higher scientific training of engineers.

"The evidence of that work is seen in the lives and labours of the many distinguished men who have studied within the College walls, pre-eminent among them, the late John Hopkinson, twice President of the Institution of Electrical Engineers, an engineer, a citizen and a man, whose name will live in the history of Engineering, and whose memory is cherished by all who knew him.

"The Institution rejoices that this good work is being maintained and extended, and trusts that the efforts of the Owens College may be crowned with an ever-increasing measure of success.

"Given under our hand and seal—

"WILLIAM EDWARD LANGDON, President.
"JOHN PERRY, Member of Council.
"WALTER G. MCMILLAN, Secretary.

"*February 27th*, 1902."

We will now resume the discussion on the papers read at the previous meeting by General Webber, by Mr. Trotter, and by Mr. Aspinall. But before doing so I shall call on Mr. Trotter, who desires to make a slight addition to the information contained in his paper.

Mr. A. P. TROTTER : At the close of the last meeting a considerable number of members presented themselves for tests at from 100 to 500 volts. Unfortunately some 40 or 50 had to be turned away owing to want of time. Some of these were afterwards measured at the Board of Trade laboratory. Altogether 170 tests have been made on 80 persons. Of these, 33 persons were tested after the meeting, and 47 at the Board of Trade laboratory. The results are shown in table (see page 778). Mr. Trotter

Some of them are easily tabulated, but most of the foot to hand tests are rather difficult to state concisely. The first section of the table represents the tests from finger to finger, the number of milliamperes taken, and the number of persons who took them. It will be found that from 1 milliampere down to 4·5, 88 per cent. of the persons took less than 5 milliamperes, and therefore could not feel more than a tingle at 100 volts. The others received slight tingles, while two of them took as much as 10 milliamperes. From foot to foot, standing upon two iron rails with 500 volts between them, 17 persons received less than one-fourth of a milliampere, and 80 per cent. of them a current that they could not feel at all, although the experiments were made on them just

Mr. Trotter.

	Finger to Finger.		Foot to Foot.			Foot to Hand.		
	Milliamperes.	No. of persons at 100 volts.	Milliamperes.	No. of persons at 500 volts.		Milliamperes.	No. of persons at 100 volts.	No. of persons at 500 volts.
88 per cent.	1·0	1	0·0	17	80 per cent.	0·0		14
	1·5	9	0·25	1		1·0	1	5
	2·0	10	0·5	5		1·5	2	...
	2·5	7	1·0	2		2·0	1	4
	3·0	5	1·5	1		2·8	1	...
	3·5	1	1·75	1		3·0	2	1
	4·0	3	2·0	5		4·0	2	4
	4·5	1	2·5	1		5·0	2	...
	6·0	2	3·0	3		5·5	1	...
	8·0	1	4·0	1				
	10·0	2	5·0	2				
			8·0	1				
			11·0	1				
			14·0	1				
			15·0	1				
			17·5	1				
			20·0	2				
			24·0	1				
			25·0	1				
			28·0	1				
			30·0	1				
		42		50				

as they happened to come in, with their boots damp or dry, as the case might be. I may say that the foot to hand resistance of some persons measured after the last meeting was so low that I did not in their cases measure the foot to foot current, for I did not wish to run the risk of giving an unpleasant shock, and there was no time to show each individual how to turn the current on gradually. My caution, which was perhaps unnecessary, affects the percentage of the foot to foot results. Fourteen persons took a current too small to move the milliampere meter.

The finger to finger results fall on a curve (Fig. A) which closely resembles a skew frequency curve.

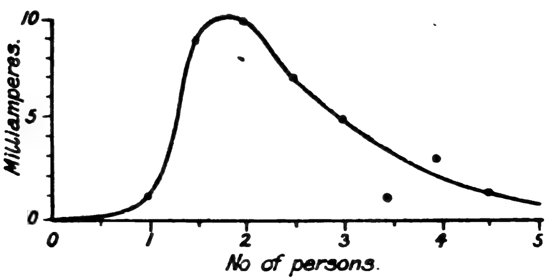


Fig. A.

In more than 20 per cent. of cases the current was between 1·5 and 2 milliamperes. Mr. Trotter.

Dr. W. S. HEDLEY: I should like to thank the Council of this Institution for the privilege of being present at this discussion. For us doctors, who have not often a chance of seeing the actual occurrence, it is, of course, instructive and interesting to have brought before us the possibilities and probabilities, and *im*probabilities of electrical accidents. It is very easy to understand the impatience felt by the electrical industry at being classed as a dangerous occupation if in point of fact statistics prove that it is otherwise. I take it that accidents in the electrical industry are not more frequent than they are in other industries which are not classed as "dangerous." I apprehend that the reason for this is *not* that all pressures employed in the electrical industry are not more or less dangerous, but because the combination of conditions necessary to produce an accident is very seldom present. Reverting to General Webber's paper; he is rather down on us for regarding the heart as a pump. I must say that if this be a fallacy, I for one must plead guilty to it. To doubt that the force that causes the blood to circulate is derived from the heart is to doubt almost the first article of the physiologist's creed. Of course we are aware that there are other forces subsidiary to it, such as the respiratory and muscular movements. And speaking for myself, I have an open mind about the possibility of other forces being at work, some force of the nature of dialysis or osmosis, or something else, to help to drag the blood through the capillaries; but I suggest that it is not necessary, for the purpose of the present discussion, to enter into that question. I think that killing by electricity is a simpler matter than that, and that known physiological facts are fairly sufficient to deal with it. In passing, I should like to say that these analogies between the correct principles of engineering and the mechanism and processes of the body are very alluring, but, of course, they are only analogies; you can very seldom follow them out to their logical conclusions. For instance, take the third molar tooth, or "wisdom tooth." No one would suppose that that is the most perfect grinding arrangement conceivable. It is a more or less stunted, irregular, and disappearing structure. So with the eye. I should be very sorry to say that the human eye is perfect as an optical instrument. We must take these things as we find them, and in the light of the knowledge that we have. The knowledge that we have on this question of the circulation, which of course is very intimately connected with electrical accidents, is that the successive beats of the ventricle drive successive charges of blood into the arteries, keeping up a pressure in them; and it is by virtue of this pressure that, if you cut an artery in the living body, blood spurts out. The stream of blood cannot escape backwards on account of an efficient system of valves; it must go forwards through the aorta, through the branch arteries, through the arterioles or smaller arteries, and through the capillaries. The capillaries constitute an obstacle to its course, and it is that obstacle which is the cause of the blood-pressure. Without that obstacle there would be no blood-pressure. Having passed the capillaries, the blood, as we all know, gets back to the heart through the veins, but by that Dr. Hedley.

Dr. Hedley. time blood-pressure has become very low. The arteries are described as "distensible and elastic tubes." As successive charges of blood are driven into them they are distended, and by virtue of their elasticity they keep up a constant pressure upon the blood. Part of the force of the heart beat is expended in keeping up this pressure, and part of it is expended in propelling the blood forward, as is shown in the pulse. In other words, and still following the language of the books, we say that the force of the heart beat is expended partly in keeping up a potential which is constantly exerting itself and becoming kinetic, *i.e.*, constantly exercising pressure on the blood, and partly in the direct kinetic element of forcing forward the circulation, as shown in the pulse.

In the light of these facts we have to consider what happens in electric killing. General Webber referred, with some approval, I think, to Dr. Bleile's experiments. I remember those experiments, and was very much impressed with them. They attempted to show that when a person is struck with an electric current, the arteries, and especially the capillaries, contract, and that owing to this constriction they thereby form an obstacle to the circulation that the force of the heart is no longer strong enough to overcome. Dr. Bleile used low-pressure currents, *i.e.*, of about 120 volts. Now it is not difficult to prove (the recent experiments of Prévost and Batelli and of Cunningham have done this) that when death occurs by low-pressure currents, it occurs by direct action on the heart, with an immediate fall in blood-pressure. If Dr. Bleile's experiments had been quite correct, if there is a contraction produced in the capillaries—if, in other words, there is an obstacle to the flow of the blood, and the heart goes on working, it follows that the blood-pressure ought to have risen. In point of fact it appears to be demonstrated by the most recent experiments that a strong current applied to the body percutaneously, that is through the skin, acts as a weaker current would do if the latter were applied direct to the heart. Now if you apply tetanising induction shocks to the exposed heart of a dog—what happens? The regular ventricular contractions cease at once, and there is produced a condition of irregular arhythmic contraction known as "fibrillar contraction"; that is to say the contraction of the ventricle loses its rhythm and regularity, and there is an immediate fall in blood-pressure. This is just the state of things as demonstrated by the experiments of Prevost and Batelli, as well as by those of Cunningham. When a low-pressure current kills, it kills by acting directly upon the heart, and it acts upon the heart by producing this condition of "fibrillar contraction," from which the mammalian heart rarely recovers—in fact it acts as a weaker current would do in a physiological experiment when the heart is exposed.

Of course it follows that if the heart is the organ acted upon on those occasions the position of the electrodes and the path of the current is a matter of very great consequence. These experiments prove that these low-pressure currents are fatal in proportion to the directness with which the heart lies in their path. This has been proved over and over again, I think. Cunningham applied the contacts to the head and to the hind leg, and he could kill small dogs with 10 volts. He applied them to the head and fore legs, and it took 80 volts

to kill them. The same thing was proved in the earlier executions in America. In, I think, the second execution that took place, the contacts were the head and the arms, and although there was a current running through the body under a pressure of 1,700 volts, another application had to be made. The position of the electrode was altered to the calf, and it was not until that was done that death was pronounced to have occurred; so that the position of the electrode makes all the difference in estimating the probabilities of death by electric currents. Dr. Hedley.

The pressures that have proved dangerous have been so very varying that it is almost impossible to go into the question. We know there have been fatal accidents from pressures of 95 or 100 volts. I know one case at least in which death has taken place with such low pressures, and I daresay others know of many more. With regard to the question of energy and work, I think some of Cunningham's experiments show that a guinea-pig weighing 1 lb. required 400 joules to kill it, whilst one weighing ten ounces took only 250 joules, so that there was some relationship between the weight of an animal and the amount of electrical work necessary to kill it. A periodicity of 130 or so is the most fatal frequency.

The condition of health that the person is in when he receives the shock is referred to in Mr. Aspinall's paper. It has been proved that alternating currents were not so fatal when the animal was anæsthetised, and therefore its muscles relaxed, in which case tetanic contractions would not be produced. That goes to show that the severe tetanic contractions have some influence on the fatal results.

But the great points that I wish to bring forward are—(1) that low-pressure currents kill by direct action on the heart, and this is usually what happens in accidents in the electrical industries; (2) high-pressure currents (*i.e.*, currents over 1,200 volts and up to, say, 5,000 volts) acting as such, kill in a different way; they act by inhibiting the respiration, and the heart stops in consequence of the asphyxia; (3) a current of enormous intensity and voltage may doubtless kill by disruption of tissue and possibly by heat coagulation of the cellular elements of the tissues. It is suggested that high-pressure currents may often act as low-pressure currents owing to bad contacts, etc. When low-pressure currents are not fatal there may be a temporary inhibition of the heart's action, and syncope. In that condition of things the statement of Mr. Aspinall with reference to the effects of lowering the head is certainly sound and sensible; it is a very usual thing to meet with syncope in cases of electric accidents where the currents have not proved fatal.

The pain that is felt by the application of strong currents we can only gather from the testimony of those who have recovered. It appears that the pain is not very great, not perhaps greater than the pain from a fairly strong shock from an induction coil. But even in the case of fatal currents I think it is proved that it is quite possible that there may be time for a person to be aware that he has received an electric shock before consciousness is lost. There cannot be time for more than this, because we know in these cases the cerebral circulation is almost immediately extinguished, and that therefore the function of the

Dr. Hedley. cerebral cortex would be simultaneously abolished. "Immediately" is a word that must be guardedly used in this connection; no result can follow its cause absolutely instantaneously. But perception is a very slow process—a nerve wave is a very slow thing; probably neither peripheral nerve nor cerebral apparatus can vibrate more than ten times a second. It has been stated by Richet that neither in the case of feeling, volition, nor thought can the process be repeated more than 10 or 12 times a second. We say "quick as thought," but how slow is this in comparison with the vibrations that you are accustomed to in light and electricity.

The after effects of electric shock are very various. You have syncope for some little time occasionally. Paralysis is, so far as I know, not very common; delirium has, I believe, been known to follow electric shock, and a very large number of cases known as traumatic neurasthenia—I believe you all know what that is. You see it follow railway and other severe accidents. A man is in a collision and he has apparently escaped without injury, and may even assist others at the time of the accident; but as days go on his nervous system begins to break down and he cannot give attention to his business; and there are a number of other symptoms which together constitute a very characteristic picture. I have seen cases of that condition as the result of electric shock. Sometimes it is a case of damages in the Law Courts, and the recovery after the damages are awarded is remarkably rapid sometimes. Still the condition is often a very real one, and has to be reckoned with.

With reference to Mr. Trotter's demonstration, I was surprised to hear that you could take 8 or 10 milliamperes without pain under a pressure of two to three hundred volts. I was surprised at that, because when I use currents from the street for electrotherapeutic purposes I find that if I use 100 volts through a resistance in series with the patient's body it is very painful. Whereas if I use just the exact number of volts that are necessary to get the current through the body it is much less painful.

A point about which I should like to ask Mr. Trotter is, how far his experiments really represent working conditions? I understand that he used a battery circuit, and I should like to be told of the physical differences there are between a battery circuit and a dynamo circuit. I suppose in a case of a battery circuit you would have to take into consideration the capacity, the internal resistance, and condition of charge of the cells, and in the dynamo circuit you would have to consider the kinetic energy and self-induction of the dynamo. Certainly these experiments of Mr. Trotter's were very instructive. They seem to demonstrate what of course was not altogether unknown before, viz., that with finger-tip or other imperfect contact and the high resistance of dry clothing, etc., you can take a large number of volts with impunity. In fact they prove what 500 volts will *not* do under unfavourable electrical conditions, but they do not prove what 500 volts *will* do under favourable electrical conditions I am sorry to say that an accident has demonstrated the latter; it was not many days after these experiments that an unfortunate man in Sheffield killed himself and

injured his friend by "larking" with 200 volts. It would indeed be an unfortunate result of this discussion were we unwittingly to throw dust in the eyes of the public by minimising the risks of electric shock. Dr. Hedley.

Mr. H. FEARON: I am an Associate of the Institution, and also one of his Majesty's inspectors of factories, therefore the last part of Gen. Webber's paper has been of very special interest to me. I think the view taken by him that the industry is opposed to the inclusion of electrical generating works and transformer stations under the Act is incorrect; and I form this opinion entirely from conversations I have had with consulting engineers, manufacturers, and electrical generating engineers. Mr. Fearon.

Consulting engineers have told me on more than one occasion that financial promoters of companies will not listen to any special precautions being taken which entail extra expense, and that therefore machinery and appliances are erected which, although first-rate electrically, are in no sense safe. I remember very well, after an inquest, asking the consulting engineer, who designed the appliance through which a man had been killed, how it was that he had passed it; and he replied that it was simply a matter of capital. Apparently that was thought to be quite a sufficient reason. Manufacturers, with whom I am in touch in my official capacity, tell me that they consider that if regulations, such as these recommendations, were made, it would be a real blessing to them, because at the present time they can only supply exactly what is specified; they cannot possibly supply perfectly safe switches, when they have to compete with firms who supply unsafe switches. One manufacturer summed it up by saying, "If you would only give us one common base line on which to work, and below which competition cannot drive us, it would be a first-rate thing for us." Station engineers have told me the same story: I have visited many during the last two years to inquire how far these recommendations were carried out, and what objections were taken to them, and in not a single case have I heard any opposition to the principles of these recommendations, but, on the other hand, in many cases they have been welcomed. Station engineers have told me that they have very little choice in the plant they have to work with; it is generally left to the consulting engineers. Again, when they take up a new appointment they find the plant old and often unsafe, but they cannot get alterations made, partly because the electricity committees over them do not realise the danger; also they have told me that consulting engineers do not like their work overhauled. I remember the pleasure of one engineer when I told him that the electricity committee of his corporation must be prepared to be prosecuted if they did not protect their switches—which he had over and over again asked should be protected but had been refused. I also very well remember a mains superintendent's pleasure when I told him that I was going strongly to recommend that his transformer cases should be efficiently earthed; he begged me on no account to mention that I could not enforce it. Although some engineers have thought that some of the recommendations were rather too stringent, others have suggested not only the

Mr. Fearon. strengthening of these particular recommendations, but additional recommendations which ought to be included. I would like to repeat that I cannot remember a single case in which any real friction has arisen, and to record the splendid way in which generating station engineers have carried out these recommendations, although they knew perfectly well that a great many of them could not be enforced legally. Therefore, from these different opinions, I do not think that the industry really opposes its inclusion under the Factory Act.

Turning to the recommendations themselves, there is unfortunately an important omission from the paper, namely, that these recommendations only apply to high-pressure stations—350 volts alternate and 700 volts direct—and that they do not apply to low-pressure stations at all. They may be summed up briefly in five general principles, all of which I believe are thoroughly sound, and no exception has been taken to them. (1) That the metal which is not part of the circuit should be earthed; (2) that the live metal should be protected with insulated material; (3) that no work should be done on high-pressure metal except in cases of urgent necessity, and then only by skilled men; (4) when work has to be done on high-pressure metal, proper safeguards such as gloves and insulated mats should be supplied; and (5) artificial respiration should be thoroughly understood. I believe those principles are perfectly sound.

General Webber asks that the following points may be considered: "The power of rendering it impossible for any person inadvertently to touch two parts of all apparatus which differ opposingly under high pressure, as laid down in III. and VI." With regard to switchboards, I believe there is no difficulty whatever in designing new boards to meet these requirements, and many of our best engineers have already done so. Although there may be certain difficulty in bringing old boards up to the standard, it certainly can be done, and I know that a great many station engineers have already done it. On running machinery there are three points to be considered — the terminals, the collector rings, and the commutators of direct-current machines. I think those are the only bare parts. There is no difficulty about covering up terminals. It is generally done in new work, although it was not done a very few years ago; and there are still a great number of terminals on high-pressure machines which are not yet, but could well be, covered. Collector rings cause more difficulty; but they need very little attention when running, and they are already in a few cases covered up with glass covers. Commutators of direct-current machines really cause the chief difficulty, because a single sparking brush may have to be adjusted when it is running, and it will be very difficult fully to carry out this recommendation in this particular case.

Mr. Joyce. Mr. S. Joyce: I was especially interested in Mr. Aspinall's statement that when burning occurs the victim seems to be more or less protected. To make the matter clearer to myself I made a few calculations, which I have put into a table (p. 785), that gives some rather interesting results. I have assumed that the real resistance of the body, if we can make an efficient contact, is 500 ohms, but that the

CONDITIONS UNDER WHICH BURNING TAKES PLACE AT 2,000 VOLTS. THE RESISTANCE OF THE BODY IS TAKEN AS 500 OHMS PLUS CONTACT RESISTANCE. Mr. Joyce.

Local Resistance R.	Total Resistance R + 500.	Current C.	Watts in Body 500 C^2.	Watts at Contacts C^2 R.	Equivalent C.C. Water Boiled per Second from 35° C.
0	500	4·00	8,000	0	0
10	510	3·92	7,683	157	0·58
50	550	3·63	6,588	672	2·48
100	600	3·33	5,544	1,122	4·05
200	700	2·85	4,061	1,639	6·06
400	900	2·22	2,464	1,980	7·32
500	1,000	2·00	2,000	2,000	7·40
700	1,200	1·66	1,377	1,956	7·23
19,500	20,000	·10	5	195	0·72
199,500	200,000	·01	0·05	20	0·07

resistance in practice is greater than this owing to the more or less imperfect contact. I have called that imperfect contact "local resistance" in the first column of the table. Assuming that the shock is taken at 2,000 volts, with very perfect contact indeed, you will see that the energy expended in the body may be as much as 8,000 watts. But even if there still be a very good contact, the local resistance being only ten ohms at the contacts, we reduce the energy expended in the body to 7,683 watts, with a difference of 157 watts expended at the contacts; and this we may call the energy expended in burning. The maximum energy possibly expended in burning would be when the contact resistance is 500 ohms, and then as much as 2,000 watts could be so expended. I think, therefore, that Mr. Aspinall's conclusion, that protection results from this burning, may not be quite the case; because with a resistance of 50 ohms we get as much as 672 watts expended in burning, with 6,588 out of 8,000 expended in the body. In order to assist the appreciation of what this burning may be, I have entered in the last column of the table the energy expended at the contacts, expressed in terms of the number of the cubic centimetres of water raised to boiling point from the normal temperature of the body, say 35 degrees centigrade, and this shows that a very considerable quantity of water can be raised to the boiling point even in one second. The worst case is where the maximum burning occurs when nearly 7½ c.c. of water can be raised to boiling point per second at 2,000 watts. I have also given some figures in the table showing cases where very imperfect contact is made, where the contact resistance

Mr. Joyce. practically extinguishes the resistance of the body altogether as an important item of the circuit; there still considerable burning results, but the shock itself may be reduced to a very small amount.

With reference to one or two other points in the paper, it seems to me the question is rather one of the current which can produce such a serious effect as to cause death. We are rather apt to speak of high-pressure and low-pressure circuits, but, after all, seeing the variable resistance which may be introduced into the circuit owing to the more or less perfect contact made with the body, it seems to me that even what we are sometimes apt to call a low-pressure circuit of, say, 200 volts may be as dangerous as a high-pressure circuit of 2,000 or more volts, according to the nature of the contact. I am sorry that Dr. Hedley was not able to give us any figures showing the effects of certain currents on the body. It appears to be a mistake to suppose that a current of a few milliamperes is more dangerous when produced by 2,000 volts than it is when produced by 20 volts. It must surely be the energy expended in the body which produces the damage, and that is, of course, quite irrespective of the pressure producing it, when we have eliminated the contact resistances.

Dr. Legge. Dr. T. M. Legge: I have to express to the Institution the thanks of the members of the Factory Department of the Home Office for the courtesy you have extended to them in inviting them to be present at this discussion. I have read most of the papers that have been written on the subject of death from electric shock, and have been considerably confused by the varying views as to the causation. Therefore I will not recount them; but there is this to remember, that the one fact which is absolutely certain is that the post-mortem appearances that are presented from electrical shock, whether in man or in animals, are always the same, and show that it is the result of asphyxia or suffocation, the right side of the heart is always engorged with blood, the lungs are congested, and the blood is collected in the great veins of the trunk. It seems, therefore, possible to exaggerate the importance of trying to determine whether this is due (1) to primary inhibition of the respiratory centre followed secondarily by failure of the heart, (2) primary inhibition of the cardiac centre followed secondarily by failure of the respirations, (3) direct action of the current on the heart itself, and (4) contraction of the arteries and capillaries, pressure thereby being set up, which the heart is unable to overcome. All those views have been supported by eminent physiologists. I think the explanation of the variations is due first to the different kinds of animals that were experimented on. The results of experiments on dogs and cats give different results from experiments with guinea-pigs and rabbits, which are far less susceptible to electric shock. Then again, I think it is due to the failure to appreciate sufficiently the importance of what is meant by strength of current rather than mere voltage, and lastly to the differences resulting from the point on the body at which contact was made. I believe with Dr. Hedley that the most valuable experiments are those of Prévost and Baccelli. Their two main conclusions, the results of some 170 experiments, are that—(1), with high-pressure alternating currents on dogs, arrest of respiration is always the first

thing, and in those cases artificial respiration is successful; (2), with low tension, 170 volts or less, there is no effect on the respiration, but the heart is thrown into a condition of fibrillary contraction from which it does not recover, and in those cases artificial respiration is unsuccessful. But he finds that if within a very limited period of time (fifteen seconds), while the heart is in that state of fibrillary contraction, a high-tension current is passed through, the heart will begin to beat; the respiration will cease, but that can be restored by artificial respiration. With regard to the question of artificial respiration, I know the recommendations that have been published by the *Electrical Review*, and I am not sure whether the time has not now come for them to be somewhat revised, and a little more information given than they contain. I have also seen the recommendations and suggestions issued by Mr. Cottrell, of Liverpool, to the *personnel* of his department with regard to accident from electric shock. I regret to see that he makes no allusion to Sylvester's method in the paragraph dealing with artificial respiration; he relies entirely on Professor Laborde's method of rhythmical traction on the tongue. As far as I know, the *rationalé* of Professor Laborde's method rests on the assumption that the respiratory centre in the brain is intact, and that if that can be stimulated natural respiration will ensue. The nerve supply of the tongue is such as to bring this about when traction is made upon it rhythmically. But if the respiratory centre, as is most probable after electric shock, is in a state of partial or complete paralysis, and unable to appreciate these messages, it seems to me important that Sylvester's method of artificial respiration should be used in addition to rhythmic traction on the tongue. Dr Legge.

Mr. H. M. SAYERS: This series of papers is full of interest, and no one in the few minutes which he may fairly take up can properly deal with all the points that rise to his mind. I shall therefore try to confine myself to one or two particular parts. In the first place, a personal experience of shock has been my lot on two occasions. When I say shock, I mean shock that has deprived me of consciousness. On one occasion I took a shock from the right hand to both feet, making a shunt off a lighting circuit. The number of volts could not have been more than 400—that is to say, the virtual volts from a Brush arc-lighting machine. Doubtless the undulations gave considerably more than that. The effect was to knock me down. I lost consciousness and power, but they returned almost at once; in fact, I was even aware of the bump of my head upon the extremely hard pavement upon which I fell. It was a cast-iron tramway, as it happened. I had a slight burn on the fingers, but beyond that and the nervous weakness for a few hours afterwards nothing followed. Mr. Sayers.

The second time I managed to put myself in circuit with a Brush arc-lighter. It was one of the old "40-light" machines; therefore there were at least 2,000 volts in effect. What else there was I do not know, but I broke a circuit in which there were about 32 arc-lamps and about six miles of underground cable, so that there was probably considerable "extra current" as well. Happily I was not grasping anything that was sufficiently large or strong to resist the muscular

Mr. Sayers. contraction. I fell away instantly. I lost consciousness very rapidly, but I recovered it almost as rapidly. I had a pair of pliers in my hand. I heard those pliers fall to the ground, and I must have heard that after I recovered consciousness. When I looked for the pliers I found them about 10 ft. away from where I was standing; so that the time taken for those pliers to fly 10 ft. and fall 3 ft. measured the time of the loss of consciousness and the recovery of consciousness as regards sense. On that occasion I took the current from hand to hand, and there again no serious consequence followed. I had some rather sore burns, and was considerably shaken up. Very rapid loss of consciousness follows on severe shock from other causes. I happen once to have been stunned by a blow on the head which caused a severe scalp wound. I was utterly unconscious of the pain, but whether that was actual unconsciousness or due to loss of memory, I am not quite certain. It was a day or two after the accident before I could remember with any sort of clearness what had led up to the accident, but no memory of pain came to me at all. In the same way with a severe electric shock, in both cases in which I have suffered them there has been no pain. There has been a very slight tingle, and the sensation that one gets from a low voltage "shocking coil" or a small magneto machine, but nothing approaching pain.

With regard to the question of how a shock kills, after the medical evidence we have heard to-night it would be foolish of me to issue my *ipse dixit* or to discuss the matter at all. I would like to point out, however, that Dr. Margaret Cleaves has collected a very large amount of evidence as to fatal shocks on human subjects, that she has published a collection of facts which have been republished in this country in the *Electrical Review*, and perhaps something may be learned by those capable of judgment from her study of the facts. As far as I have read them, they seem to be simply a record of facts, and apparently no attempt has been made to generalise from them. I do not say that in any tone of complaint, and I mention the work because I think it is a rather valuable mine of information.

Dr. Hedley certainly rather astonished me by talking about the difference between a low-pressure current and a high-pressure current. I want to know this. If one is shocked by a high pressure, other things being equal, the current must be in excess of that given by the low pressure. I am not disputing that a high pressure may kill by its action on the respiratory centres; but if the current that is sufficient to kill by action on the respiratory centres is in excess of that which is sufficient to kill by action on the heart, are we to understand that a small current will stop the heart, and that a large current sets the heart going again? That is the only electrical conclusion one can draw from the language used. It does not seem logical, and I would like to know what is meant.

I may say from what I have heard and seen, I judge that the cause of death in electric shock is generally asphyxia. The fact that the whole of the blood in the body is black—blacker than ordinary venous blood—seems to prove that beyond any sort of question; and that that blackness is due to want of aëration is proved by the fact that the blood

becomes scarlet again on exposure to the atmosphere even after death. Mr. Sayers. The extreme blackness, I should like to suggest for the consideration of medical men who should be in a position to judge, may be due in part to the large amount of waste material thrown into the blood from the excessive muscular contractions. The large amount of waste material and the absence of aëration seems to me to account for that particular phenomenon. I imagine that the suspension of the action of the heart is temporary, and that the heart tends to resume its proper rhythmic contraction after the disturbing cause has passed, if the damage to the nervous centres has not been too great. I wonder if there is anything in the following suggestion? The ganglia which I believe control the heart's action are imbedded in the substance of the heart itself. They are therefore surrounded by a mass of muscle and blood, which are relatively much better electrical conductors than the nervous matter of which the ganglia are composed. They may therefore be shielded to a very large extent from the current which is passing through the mass of the heart. I believe that the ganglia which control the respiratory action are not so shielded; and the difference between the sensitivity of the two sets may be simply due to the fact that the one is shunted by the conducting mass in which it is fixed, and that the other is not so shunted because the mass is not so conducting.

There is one more thing I should like to say. We have heard from the Home Office of its most benevolent intentions towards the industry. We never doubted it. The feeling of the industry I think I may say I know a little more about than do the inspectors from the Home Office. The central station engineers whom they had the good fortune to meet, seemed to me to have been of a somewhat flabby description. If they could not get their directors or their committee to make their switchboards safe to human life, I think it was not only the switchboards that wanted scrapping. Our feeling about it is this: The factory inspectors of the Home office have been dealing for many years with textile factories and places of that kind where there are large numbers of women and children of both sexes, who are crowded together in close proximity to moving machinery. They have no technical knowledge; they have hardly sufficient consciousness of the dangers which they are close to. Therefore, they do require protection from their own ignorance and from the exigencies of the business. They also require protection as regards cleanliness, sanitary arrangements, ventilation, and other things of that kind. But a generating station, a central station, is an entirely different arrangement. Where there are 600 people in a cotton-spinning mill, in the same cubic space you will find six men in a central station—not women and children, but men, and men each of whom knows what he is handling, each of whom knows the dangers around him, each of whom knows what he has to touch and what he has to leave alone. You find also, instead of the cheapest and roughest kind of building such as you frequently find in factories, such materials as glazed bricks. I believe that the Factory Act Regulations say that all factories must be whitewashed twice a year. Are we to whitewash glazed bricks? Another difference is this: A factory may be stopped for half an hour, or half a day or a day, with

Mr. Sayers. no serious loss and with no serious inconvenience beyond the mere loss of product; but a central station if it is stopped half a minute, plunges thousands of people into darkness and stops thousands of machines. Can any one gauge what damage to life or property may result? The factory inspector is not in a position to judge which of his precautions are likely to prevent rapid attention and rapid observation of occurrences which may cause a breakdown to the factory and a cessation of the supply which it is there to give. I therefore think that the habit of mind which has grown up—quite properly grown up, perhaps—in respect to ordinary factories, is not the habit of mind which is fitted to come into a place upon which a great public service depends, and to say, "This you shall do and this you shall not do," and which can haul you before a magistrate without anything more than its *ipse dixit*, and make you carry out its commands or commit you to prison.

Mr. Ball. Mr. W. VALENTINE BALL: I wish to refer to the legal aspect of the case. The Factory Act of 1901 has to be accepted, as it came into force at the commencement of this year. With the policy, therefore, of including electrical stations within the Factory Acts we now have nothing to do, but only to consider what the effect of that inclusion actually is. It has one peculiar effect which I do not think is generally known, namely, that it brings within the Workmen's Compensation Act all the generating stations which are brought within the Factory Acts. This comes about owing to that extraordinary system of "legislation by reference" which has been so much in vogue of recent years, and which, as applied to the Electric Lighting Acts, has been of very great disadvantage. The word "Factory" for the purpose of the Workmen's Compensation Act is defined in the Factories Acts. Now by the recent Act the meaning of the word "factory" was extended so as to include generating stations, *i.e.*, "Any premises or that part of any premises in which electrical energy is generated or transformed for the purpose of supply or trade, or for the lighting of any place or of any hotel, railway, mine, or other industrial undertaking." So that the owner of a hotel who has his private installation to light the hotel becomes liable to pay compensation to any workman who is killed in the performance of his duty in connection with the lighting of that building. That is a very important matter for electrical engineers to consider when they discuss the question whether the proposed rules are for their benefit or not. This Act has placed responsibility upon them. Therefore, every rule which makes for the protection and safety of the workman seems to me to work a benefit to the employer as well. Whether that opinion meets with the sympathy of the meeting I cannot undertake to say. The last speaker referred to the disadvantage of applying the Factory Acts to generating stations, and he described in glowing terms how foolish it would be to whitewash a glazed brick wall. I think the meeting agrees with him upon that, but there is this important fact to remember, that a generating station will probably only employ men. Therefore many of the regulations which are made under the Factory Acts, and which are included in the new Act, have no application whatever to electrical generating stations. He also mentioned that the

factory inspectors have been in the habit of controlling industries where women and children are employed, but their jurisdiction has also extended to factories where men only are employed, and therefore any training which they have there obtained will be of use to them in controlling the new industries to which they are now introduced. Mr. Ball.

Mr. H. FEARON: With regard to the questions raised by the last speakers, generating stations are factories and not workshops, and therefore the sanitary provisions will apply to them, but they have been specially exempted from the lime-washing provisions. Mr. Fearon.

(*Communicated*).—Electric Generating and Transformer Stations are now scheduled as being factories under the new Factory Act, 1901, and in consequence all the ordinary provisions of it now apply to them, with the exception of the clause which requires factories to be lime-washed. The provision that most affects them is that "all dangerous parts of the machinery must be securely fenced"; according to the decision of the Magistrate at Greenwich Police Court in December, 1900, this includes an unprotected high-pressure live switch on a switchboard away from the running machinery. Most of the Recommendations issued by the Home Office and quoted by General Webber are not yet law, and only those which refer to covering up high-pressure metal can now be enforced.

The Home Secretary has, however, power to make Special Rules for any Dangerous Trade, as has already been done in White Lead, Pottery, Phosphorus Match, and other trades. Before any special rules become law, suggested rules must be published, written objections to them received, if necessary an inquiry held, and finally they must be laid for forty days before both Houses of Parliament. If they are not annulled during that time they become law. No such action has yet been taken by the Home Secretary.

Dr. LEWIS JONES: As much of the ground has already been covered, I propose to speak only on a few things which seem to me of interest. With regard to Major-General Webber's "heresy," as we think it, I am quite in accord with Dr. Hedley that the heart is at any rate the chief factor in propelling the blood through the system. In the mechanics of the circulation I should be inclined to say that the heart is the source of energy, and the circulation through the blood-vessels is the sink of energy. Passing now to Mr. Trotter's paper, there is not a great deal to say about such a lucid and succinct exposition of straightforward facts. It does not leave much room for discussion, and I can only say that, to me, at least, it was very instructive. I had always thought there was a good deal of danger from contacts with 500-volt circuits. As I have sat upon a tram-car and seen how near the trolley wires were underneath some of the bridges, I certainly thought the arrangement was a little dangerous. I am glad to know that an accidental touch of the trolley wire is not likely to do serious harm. Mr. Aspinall's paper provides a feast of material for discussion. I must congratulate Mr. Aspinall upon the excellent medical paper which he has contributed. It is full of most suggestive matter, and most conveniently arranged in the form of a series of questions. I propose to run through it as quickly as possible, and to do what I can to answer his questions. Dr. Jones

Dr. Jones. "1. Is every one equally susceptible to an electric shock?" I take it that everybody is susceptible, though in unequal degrees.

"2. Is a person suffering from disease more likely to be fatally injured by an electric shock than a person in good health?" To that we may answer, Undoubtedly so. There are in all communities, at any rate in all civilised communities, a number of more or less infirm people, and a little thing is enough to upset the equilibrium of some of these. Between those of strong vigorous constitution and those who are enfeebled by disease or old age there are many varying degrees of capacity for resistance to shocks of all kinds. A given shock passed through a hundred people might undoubtedly kill some and leave others unkilled. The question is on all fours with that as to whether the same amount of mechanical shock would be enough to stop all watches. But we know that some are stopped by a very little jar, while others will stand a fall to the ground without stopping. With men it is just the same, both for electric and for other shocks. There are people to whom it would be dangerous to give any sort of a shock, and that has something to do with the cases we see reported of deaths from electricity at comparatively low voltages. We are not now discussing how high a voltage a man could stand and escape with his life, or how low a voltage a man might die from. But rather the question, what is the pressure which in nine cases out of ten is likely to prove fatal; and what are the pressures which in most cases one can touch and yet survive undamaged? Apart from cases in which from various causes the vitality is low, there are diseases in which the skin is apt to be moist, and in these the electrical resistance is low. Such people would obviously derive a larger current from a given electro-motive force than people with dry or horny skin. For example, a person who returns to his work after an illness with a thin epidermis and a moist or clammy skin would be in a relatively dangerous condition, whereas a man in regular work with a dry and horny skin could stand the same pressures better. It is the horny skin of the workman which protects him best. At the trials which followed our last meeting I was unable to trust my fingers to any higher pressure than 200 volts. My skin is thin and often moist, and on that evening it was damp and close, and 200 volts from finger to finger or from finger to foot gave me all the current that I cared to take. With regard to the current which a person can carry and live, it is certain that they can carry 200 milliamperes. That quantity is sometimes applied in certain forms of medical treatment, and with certain precautions it is borne with comparative comfort. As a guess, and it is only a guess, I should be inclined to say that something like half an ampere or more is necessary to kill a patient, but that the minimum fatal current is bound to vary very widely with the condition of the patient and with the path which the current takes in him. Mr. Aspinall told us of a case where a woman was so unsusceptible to induction coil shocks that she was able to take the money out of a bowl when others could not. If one comes to medical curiosities I can cap that with the following: I remember a patient who was able to feel the simple touch of an electrode upon the surface of one half of her body, and yet felt nothing whatever of the strongest induction-coil currents

that we could apply to her through the electrode. There are these rare peculiarities. Just as there are diseases in which a patient sweats much and has a very low resistance, so there are cases where the sensory nerves are affected and there are forms of paralysis in which the strongest currents are hardly felt. Dr. Jones.

Question 3 asks, "Does the physiological condition one is in at the time a shock is received make any difference?" Undoubtedly it does, in many ways. I can quite believe that alcohol in certain quantities might enable a man to stand a larger current by, as it were, benumbing that part of the nervous system which has to do with the beating of the heart. There are nerves in the body which control the beat of the heart;—stimulate them and the heart stops. If these nerves have their action suspended by any drug such as alcohol, the heart may be able to stand rather more stress of current than before. When it comes to the condition of perspiration, I think I must disagree with Mr. Aspinall. He suggests that the wet skin, or rather the wet shirt of a person perspiring freely might so shunt the current as to protect the victim. It seems to me that with any self-respecting dynamo a wet shirt could not so short-circuit the current as to cause any great fall of potential at the point of contact. I feel sure that the person referred to who escaped with his life, escaped not because of the perspiration, but in spite of it, and that his danger was very much greater than it would have been if his shirt and skin had been dry. The fact of people not feeling a shock when they are asleep is new and interesting, and I hope to have an opportunity of trying the experiment one of these days. As to the importance of the path of the current through the body, I think most of us are agreed that the current must go through a vital part—that is to say, that there are such things as vital parts and non-vital parts. I believe that a patient standing on two conductors might carry an enormous current through the legs, enough to burn his feet very severely without being killed by the electric shock, although the secondary consequences of the burns might kill him. To kill by an electric shock, the current must go through some of the vital parts of the body. In my opinion that is generally the heart; it may sometimes be the central nervous system, but in a series of experiments I witnessed some time ago, it was obvious that a path through the heart was necessary to kill the animal. The same current which killed the animal when passed from one side of the chest to the other, when passed through the skull of another similar animal not only did not kill it, but roused it from the deepest chloroform narcosis. So there is clearly in some animals at least, and with certain pressures, a considerable importance in the path which the current takes. I think the most susceptible of the vital organs is the heart, and that, as a rule, in the fatal cases the patient dies because his heart is stopped by shock, and once his heart is completely stopped, it is almost impossible to get it started again. Whether that is the case in all fatal cases I do not know; whether that is the case in the non-fatal cases is even more doubtful because of what I have just said, namely, that the human heart once dead-stopped is not easily set going again. The respiratory apparatus is also a vital organ, and appears to be the part affected in the cases reported as having

Dr. Jones. recovered after artificial respiration. Some of those cases, it seems to me, proved too much. For example, the well-known case reported by D'Arsonval, where the patient was left twenty minutes or half an hour before any artificial respiration was attempted at all. I have the opinion that he was not so much in a state of asphyxia from shock to his respiratory system, but that he was rather in a state of suspended animation with heart and lungs still working very feebly and faintly. Mr. Aspinall in his paper recounts a similar case where a man came round spontaneously without artificial respiration after a lapse of twenty minutes.

As to burning, this I believe is a measure not so much of the watts as of the watt-hours which go through the patient. It is the long contact which gives a bad burn. One of the first people killed electrically in this country was killed by an arc-lighting machine at the Industries Exhibition. There a very careful *post-mortem* was made, and the conspicuous point about the case was that there were no morbid signs to show the cause of death except a minute red spot or slight burn on one finger. So electricity may kill with slight burning, or may fail to kill and yet cause great burning. The amount of burning certainly depends upon the duration of the contact, also no doubt indirectly on the potential at the point of contact, because if the E.M.F. is high enough to produce an arc between the metal and the skin, the burning at that high temperature will be very rapid and very severe.

With regard to the relative dangers of alternating and direct current, one is tempted to draw comparisons from the relative painfulness, but I do not think that is much of a guide. Alternating current is most easily felt certainly. When using an alternating current in an electric bath, the usual pressure for patients is about five volts; whilst with direct current without interruptions one can bear with ease and comfort 20, 30, or 40 volts. But I think the difference between these figures is no measure of the relative danger of the two forms of current supply.

"8. Cannot the doctors give us a more certain method of ascertaining whether a man is dead or not?" That is sometimes a difficult question to answer. Sometimes it is a help to scrutinise the pupil of the eye and the cornea, or transparent part of the eye. If a patient is dead, the cornea is dim and flaccid. The iris, too, loses its circular form, and the pupil accordingly is inclined to assume any shape according to the pressure applied to the globe of the eye. But even medical men may occasionally have a difficulty in settling whether a patient is really dead—sometimes it is very difficult. With regard to the treatment of those who receive severe shocks, I would say that the behaviour of the engineer who inverted the injured man and thumped his chest was admirable. A blow over the heart is perhaps the best way of trying to make the heart give one more beat, and if the heart can be got to give one more beat it will very often go on beating afterwards. The heart has a tendency to beat at a certain rhythm; if it once gets thrown entirely out of step it very often fails, in the higher mammals, to get into step again. With regard to artificial respiration

I feel a little uncertain what to say. It might be extremely serious for a medical man to say that he thought artificial respiration was not very valuable. I should shrink from saying that until something better could be proposed. So I will just say this, that there are a certain number of those who receive bad shocks who are dead, incurably dead, and that no amount of artificial respiration will revive them. But it seems quite clear from the reports of engineers that there are a few who are, as it were, knocked out of time by the shock they have received, and in them the artificial respiration applied does certainly seem to have helped to bring back consciousness, whatever may have been the physiological condition of their insensibility. So I would certainly support and endorse the using of artificial respiration in every case of insensibility from electric shock until we have something better to take its place; and in addition I would advocate the elevation of the lower limbs and trunk, the rhythmic traction on the tongue which has lately been advocated, and a smart tap over the region of the heart, repeated a few times in the course of the first half-minute. Dr. Jones.

Dr. HENRY MCCLURE: I am approaching the subject as a medical man, yet altogether from the physical side, and with your permission I wish to read an extract of a paper of mine which was read as far back as 1893. The paper was an attempt to explain the action of electricity on a certain organ of the human body, and in the course of my remarks I said: "I might have given my paper another title, possibly more appropriate, and that title would have been, 'A Plea for more Consideration for the Dielectric Tissues of the Human Body.' Yet in order to put the matter in a more concrete form, I have chosen to take this organ to illustrate my thesis. My contention is shortly as follows, that the tissues of the human body are no exception to the general law that all opaque bodies are necessarily conductors, and transparent bodies insulators or dielectrics, more or less perfect. These deaths from lightning or from shock would be impossible if the human organism were a conductor of electricity. My argument is this: That of course electricity passes through the organism, but that the electrical energy passes into the transparent tissue of the human body, the dielectrics, as we know it does outside. We know the electrical energy does not pass through the wires of the cable—it passes outside the wires; and this electrical energy passing into the human body, from being dynamic becomes static, and is entangled in these tissues; therefore we have in the dielectric a tension along the lines of electrical propagation and pressure at right angles to this. This would no doubt lead to a diminution of calibre of the arteries. We have the electricity entangled in the arteries and contracting them, and the heart, beating against the arterial constriction, fails in the attempt. Of course the nerves are in this same condition of strain. Dr. McClure.

So the whole question, to my mind, is the condition of strain in the dielectric tissues of the human body, and if by any means we can relieve that strain it will be an advantage. We find that artificial respiration sometimes is exceedingly helpful, and from the observations of Mr. Aspinall, alcohol would seem to have some protective influence. Alcohol is a vasomotor dilator, so is nitrite of amyl and so is nitro-

Dr. McClure.

glycerine. We find that men taking nitrite of amyl and nitro-glycerine can take a bigger shock than others who have not taken those drugs. We find that the skin offers an enormous resistance to the passage of a current of electricity; if it were not for the many passages through it, the application of electricity to the human body would be impossible. It is generally accepted that the blood and its interstitial fluids are the true conductors of the current. But Erb calls attention to the fact that nerve and muscle offer a much greater resistance to currents traversing them transversely than longitudinally, five to one in nerve and nine to one in muscle. I consider this has an important bearing on the subject under discussion. The solution seems to me that the transparent elements of nerve and muscle are in the way of the current when traversing them transversely, so much electricity apparently disappears; it is used up in producing strain of the medium. In the longitudinal direction nothing is in the way; the electricity flows in the fluids between and outside the fibres. I think we must admit that when electricity encounters a dielectric some of the electrical energy seems to disappear, but it is not lost; we know that whenever energy disappears in one form, it reappears without loss in another. That is, that the electrical energy which has seemingly disappeared has reappeared as molecular strain, or rather strain of atoms within the molecule, and we could quite conceive this strain to go on to disruption and functional tissue destruction.

Mr. S. F. Walker.

Mr. S. F. Walker: I wish to give you a few details of the Sheffield accident to which reference has been made. The man was not killed by electric shock at all; he died *after* electric shock. I happened to arrive in Sheffield the evening after the inquest. I went down to the music-hall where the accident happened, and the manager kindly allowed me to see the whole thing, and explained the accident to me. The service is three-wire alternating 400 volts between outers, the middle wire earthed. There was a bracket made from brass tube of the usual form in the lavatory, and a lead floor underneath it, very wet. There was no switch for the lamp on the bracket; they switched the lamp off by taking it out. There was no lamp in at the time. There were some steps going down to the lead-floored portion of the lavatory path, and the bracket was almost out of reach, just above the steps. The man knew just enough to make a fool of himself. He reached up and caught hold of the bracket with both hands with a firm grip, intending, apparently, to pull it down. He tore the bracket out of its place, made connection between the bracket and one of the wires, presumably the live wire, by the sharp edge of the bracket cutting through the insulation, and he got a shock which drew him up with his feet off the floor. Of course he broke circuit then, but the muscles were apparently very much contracted, and did not immediately relax. He had a terrible fright, and had lost will power. He called out to his mate that it was killing him. His mate pulled him down pretty violently. The other portion of the floor was hard concrete; he fell on the back of his head, and my view is that it was concussion of the brain, or something similar to that, which killed him. He spoke after he had fallen on the floor; he said he should be all right in a minute.

At the coroner's inquest no representatives of the Corporation electrical supply department were present. Strong remarks were made at their not being there, though no notice had been given them of the inquest. No medical evidence was presented, and no *post-mortem* was made. I wrote to the coroner and asked him if he would kindly put me in the way of obtaining a copy of the medical evidence. I have his letter in which he says there was no medical evidence called. I would suggest that the Institution should memoralise the Home Secretary, or whoever is the proper official, that in all cases of this kind, where it is at all practical, *post-mortem* examinations should be made. I feel sure we should get much very valuable information from them. Mr. S. F. Walker.

Mr. M. B. FIELD (*communicated*): I am heartily in sympathy with the attempt which Mr. Trotter has made to allay the misapprehension under which the non-technical press and the man in the street labour as regards the dangers inherent in 500-volt shocks. Nowadays it is not altogether an unusual occurrence for one to overhear, perhaps in a railway train, at a restaurant, or elsewhere, some non-technical wise-acre, while dilating upon the mysteries of electric traction, explain that if any one should be so foolish as to touch the third rail he would be instantly reduced to a charred mass; or failing that, make some other equally extravagant statement as to the inevitable result of a momentary contact with a 500-volt main. Mr. Field.

Mr. Trotter's paper will, I hope, do much to remove such exaggerated notions; but I am almost afraid some, after reading the paper, may be inclined to rush to the opposite extreme and consider that the dangers of 500-volt circuits are merely mythical. Mr. Trotter says, for example, on page 766, "Neither a man in the street nor a man on the car runs any risk in taking 500 volts skin to metal." Personally I do not like to see such statements published by an eminent authority without a caution being appended. As I shall afterwards show, I consider a very great risk *might* be attendant upon such a procedure. Mr. Trotter goes on to say in explanation that he has frequently grasped a live trolley line in both hands from the top of a car. This may very well be done without feeling a shock, seeing the car itself in dry weather insulates the experimenter very perfectly. Grasping the handrail and flicking the trolley wire with the finger (supposing the handrail grounded) is to most people a painful operation, though by no means dangerous; but grasping both handrail and trolley wire, skin to metal, will, I think I might say in 75 cases out of 100, give a shock of sufficient severity to render the experimenter powerless to release his grasp—and therein lies the danger—a point not brought out by Mr. Trotter.

The danger to life involved in a shock is not solely dependent on the voltage. Cases of shock of 250 volts and less have been known to prove fatal: while others at 5,000 have not been attended with loss of life. The question as to whether a shock will prove fatal or not is probably decided by a large number of factors: 1st, the physical peculiarities of the subject; 2nd, the strength of current traversing the body; 3rd, the path traversed; and 4th, the duration of the shock, etc. I should be inclined to make the following classification of shocks :—

Mr. Field.

(a) *Painful, but not dangerous*:—When two metallic bodies (*e.g.*, terminals) are grasped one in either hand, but the potential difference between them is sufficiently small to allow of them being voluntarily let go again; or when the body is momentarily placed in circuit with a moderate voltage[1] without grasping, or in such a way that grasping is impossible.

(b) *Dangerous, if prolonged*: — When the potential difference is sufficiently great to cause the hands involuntarily to grasp the terminals if they touch them, and the victim is powerless to open the hands, though able to cry out intelligently or otherwise.

(c) *Dangerous, though not necessarily producing immediate unconsciousness*:—When the potential difference is still greater, so that, while it is impossible to release the grip, the victim is unable to utter any cry whatever.

(d) *Very dangerous, unconsciousness ensuing immediately on contact*:— Considerably higher potentials than the foregoing; momentary contact produces unconsciousness and perhaps death.

It is impossible to lay down limits of voltage for the above cases; they depend so much upon circumstances and individuals: but I will instance here a few typical cases that have come to my knowledge:—

(1) I have seen a man writhing with his hands grasping two wet water-plates with only about 80 volts between them. He could not release them, but shouted intelligible instructions. (2) I myself received a very severe shock from a 2,000-volt alternator running unexcited. I doubt if it were giving as much as 200 volts. I was standing on the top of a concrete wall forming part of a reservoir, in very powerful sunshine. My left hand came quite accidentally against a wire leading to a water resistance dipping into the water, and it immediately gripped the wire firmly. I was powerless to release my grip; but running along the wall I sprang down (about a 5-foot drop), by which action I tore myself free of the wires. While in contact I could distinctly feel the current, first in the right, then in the left leg, at each step. I shouted, but could give no clear directions. (3) A man standing on fairly dry ground was unable to release the handle of a fuse-box which had become alive from a 500-volt tramway circuit. He shouted and was pulled off. (4) A linesman standing on the handrail of a car was unable to release a trolley wire at 500 volts he had gripped. He shouted and was pulled off. (5) A man tripped over a coil of wire and made contact for an instant with the brush gear of a 550-volt machine. The contact was only momentary, for, as he lay on the floor he was quite clear of the machine. During his fall the brush holder had, however, scratched and entered the skin of the neck, and such a severe shock resulted that resuscitation methods were resorted to for nearly half an hour before any signs of life were manifested. Immediately after the shock his face was slate-coloured, with a greenish tendency. As he revived, this colour changed to yellow-green, then to yellow, and finally remained very white. He could not for some time articulate any sounds, but endeavoured to do so. (6) A few years ago I saw a poor fellow who had been killed by 2,000 volts alternating. He uttered no cry (as

[1] Perhaps up to 800 volts.

far as I could ascertain) but stood stiff and erect, grasping the fatal switch, which had become alive, for fully half a minute until the circuit was broken, when he instantly collapsed. Mr. Field.

It should be borne in mind that moderately low voltages (*e.g.*, 500 volts) may be very dangerous if contact be made at a part of the body where an open sore or cut exists—this may easily be the case on a workman's hands (*vide* Case 5).

There is one important difference between high-tension direct-current and alternating-current systems from the point of view of shocks, and it is this:—With a direct-current system, provided both poles be thoroughly insulated, they may be touched one at a time by any one standing on earth without running the risk of a fatal shock. For example, if the insulation to earth of each pole be 30 megohms and the supply voltage be 3,000 volts, the current flowing to earth through

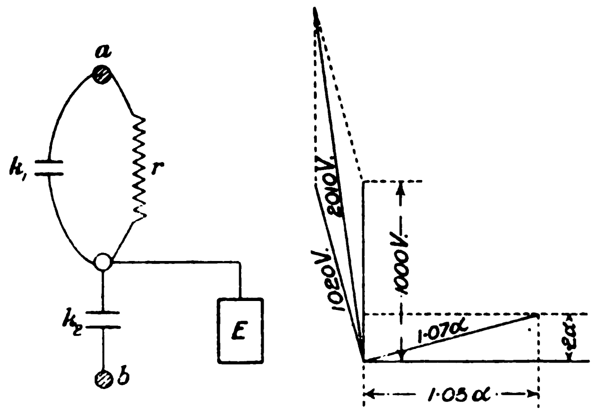


FIG. B.

the body if in contact with one pole would be less than one-tenth milli-ampere. With the same conditions, but with an alternating system, the current through the body might be several thousand times as great. If the amount of underground cable be at all large, the insulation resistance of the system plays a relatively small part in reducing the current to earth; for, owing to the capacity to earth of each pole, the body is practically forming part of a circuit of relatively low impedance through which a large current will flow. Take an actual case[1]:—

Supply voltage, 3,000; frequency, 50; capacity of each pole to earth, 3·33 microfarads.

The capacity current will be, in this case, 1·57 amperes.

Now, connect a resistance of 5,000 ohms, representing a human body, between earth and one pole (Fig. B). Assume for the time being pole *a* is 1,000 volts above earth; the current through *r* will be ·2

[1] A single-phase case is taken by way of example, though such systems would usually employ concentric cables with the outers earthed.

Mr. Field.

amperes, and through k_1, 1·05 amperes. The resultant will be 1·07 amperes. This flows through k_2, and therefore b will be 1,020 volts above earth. Combining these two voltages, as in Fig. B, we find the P.D. between a and b is 2,010 volts.

Or, if we take the supply voltage at 3,000 instead 2,010, the current through r will be proportionately increased, viz., to ·298 amperes; that is to say, as far as prevention of shocks is concerned, the insulation of the cable is only equivalent to about 5,000 ohms to earth, though in reality it may measure 30 megohms or more.

It is, of course, theoretically possible to neutralise this capacity effect in the usual way by connecting a corresponding self-induction in parallel, as in Fig. C.

If these be perfect capacities and self-inductions, the current through k_1, l_1, r, would be zero; whereas, through k_2 and l_2, comparatively large currents would flow in opposite phases: v would likewise be zero. It certainly seems remarkable that although no current whatever flows from a to earth either through k_1, l_1, or r (representing the human body), an appreciable current is flowing between earth and b in each of the circuits k_2 and l_2.

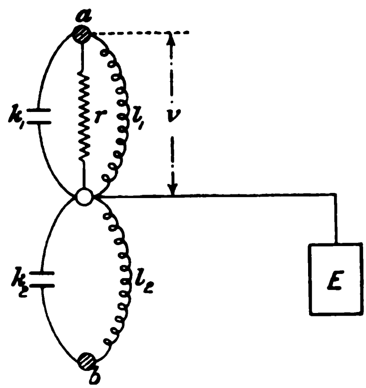


FIG. C.

Of course, this method of connecting self-inductions between the mains and earth to overcome shocks is not really practicable; firstly, because it is not possible to obtain sufficiently pure self-inductions and capacities, *i.e.*, devoid of dielectric and magnetic hysteresis, ohmic losses, etc.; secondly, true compensation is only obtained at a given frequency, and if this frequency be departed from by only a small percentage, currents of fatal magnitude would probably traverse the resistance r.[1]

Coming now to a more practical point, I would like to touch upon the treatment of those rendered unconscious by electric shock. It is well known that in cases of collapse, such as result from severe electric shock, it is highly beneficial and sometimes imperative to use artificial means to stimulate the action of the heart, such as the hypodermic injection of ether, brandy, etc. Now, it is quite possible that after such an accident, a medical man, hastily summoned, would not be provided with the necessary apparatus for the treatment referred to above. To

[1] If k and l be arranged to neutralise each other at a frequency n, then the combination of k and l for a frequency $n + \delta n$ is equivalent to merely a single capacity of value k, but working a frequency $2\delta n$, instead of $n + \delta n$ if δn be positive, or to a single self-induction of value l with a frequency $\frac{n^2}{2\delta n}$ if δn be negative.

meet this emergency I have hitherto recommended that all high-tension sub-stations and generating stations be provided with a small sealed case containing a hypodermic syringe, together with small phials of necessary drugs. I might mention that Messrs. Park, Davis & Co. supply aluminium cases which can be carried about in the waistcoat pocket, containing a hypodermic syringe, together with hypodermatic tabloids of strychnine nitrate, cocaine hydrochlorate, morphine sulphate, etc., as may be required. One of these tabloids has only to be inserted in the barrel of the syringe and the latter filled with pure water for the apparatus to be ready for use. Mr. Field.

One engineer with whom I was acquainted on the Continent claimed to have saved several lives by the timely injection of ether. The medical profession in England seems, however, to consider it altogether beyond the province of unqualified persons to apply this restorative, and I should be glad to elicit the views of medical men on this point.

Mr. HENRY HALL (*communicated*): Not being an electrician, I feel some diffidence in taking part in the discussion. I gather that the effects of electric shocks on different individuals and on animals are very variable, due chiefly, no doubt, to the manner of the application of the electric force. This force itself, I take it, should be equal and constant under similar voltages and pressures, and should always produce the same results under a given set of circumstances. Mr. Hall

It will perhaps be more to the purpose to mention that in mines we are now using electricity as a motive power for various purposes, such as coal-cutting, drilling, pumping, haulage and, in one instance, for winding the minerals to the surface and for raising and lowering the workpeople. This particular mine is unique from the fact that there is neither smoke nor steam to be found on the premises. These installations and fittings are often somewhat exposed, and men and boys are passing to and fro all day long, but anything in the nature of a serious injury from shock is almost unknown, although slight shocks are quite common. The voltage is usually between 200 and 500. In the early days of electric lighting underground, some twelve years ago, there was one case in my district of a death by shock, and in this case it was said that the sufferer had interfered with the switch. Except as an interesting subject of scientific inquiry, it does not appear to be of much practical importance to define the precise voltage and the particular part of the body from its application to which death will result. To a layman it seems more to the purpose *and a better policy* to give a wide margin of safety, and to adopt every possible precaution so that the development of electrical application may not receive setbacks through unfortunate accidents. One of the writers has referred to the accident in the Liverpool streets caused by the overhead telephone wires falling on the trolley line, and he tells us that there was at the time a concurrence of circumstances not likely ever to occur again. Now this standpoint may be scientifically correct, but in this everyday world people pay more heed to facts than to theories, and I believe that two or three repetitions of this accident would have led to the tramcars being withdrawn from the streets.

Now, a word or two on General Webber's paper which deals

Mr. Hall. almost entirely with legislation. It is natural to kick in response to what one looks upon as an unjust attack, but is the proposed or effected legislation unjust? Is it not a fact that all industries, the carrying on of which entails danger either to those engaged in them or to the public, have been subjected to official inspection and more or less stringent rules. Your industry cannot escape being classed in this category. To the initiated the risk of injury may be small, but we cannot all be electricians, and I think it must be admitted that to the uninitiated there exists a real danger and one much more insidious and difficult to guard against than is the case in other industries.

General Webber tells us that the official department having control of these matters has assumed a somewhat militant attitude, and that rules are being forced upon the industry which are neither necessary nor desirable. I have had a very long and intimate acquaintance with the department in question, and always found that any suggestion of new rules which might hamper an industry were very coldly received and seldom adopted. Almost in all cases the official precautions that are sought to be enforced are just those which the best firms adopt voluntarily, and the only effect of legislation is to bring the laggards into line.

Mr. de Grave. Mr. L. W. DE GRAVE (*communicated*): I am somewhat surprised that in dealing with the subject of shocks no mention has been made of the time for which the shock was taken, nor of the "feeling" at various intervals of time up to the point at which the experimenter was satiated. I was led, some seven or eight years ago, when designing cables and accessories for electric distribution in mines at the pressure of 500 volts, to pay close attention to the effect of shocks, and have carefully followed the matter up to the present. Early last year, the unfortunate occurrence of several fatal accidents in mines induced me, at the request of the Institute of Mining Engineers, to publish my investigations on the subject (*Trans. Inst. Mining Engineers*, 1901, vol. 21, page 136; vol. 22, page 35; and vol. 22, page 265).

Some abbreviated extracts bearing on the subject under discussion may be of interest; I would, however, point out that in the majority of pits the conditions are very far removed from any of those brought forward by the authors of these three papers, both as regards cramped positions and moisture—both human and natural.

"A shock is the passage through the body of a small electric current, causing nervous and muscular contraction or cramp, and (if there be sufficient current passing for a sufficient time) the stoppage of the heart's action, due to the nervous and muscular contraction round the heart exerting a pressure on it. This is not generally accepted in the medical profession, but there are many indications that it is the cause. *Post-mortems* have resulted in the stock verdict of 'asphyxia or syncope due to electric shock.'"

In connection with this portion of the subject I should like to ask General Webber whether "the underlying fallacy in that the heart is a pump" is not intended to be very largely qualified by the "only" in the following line, and that the heart may be considered, at all events, as one of the pumps, if not the important pump, of the body?

Mr. de Grave.

Dr. R. N. Cunningham refers to the subject of shock in an article in the *New York Medical Journal.*[1]

I also pointed out in my paper that "muscular development," rather than difference in "constitution," was responsible for the variable effects of electric shocks on individuals, as it is invariably found that an extremely muscular man suffers to a much greater extent than one of less muscular development. In several cases of quadrupeds which have been "electrocuted" an immediate *post-mortem* (without the removal of the electric current) has shown abnormal pressure on the heart.

With regard to the time for which shocks can be endured, the Liverpool accident is an interesting case. My paper above referred to included the results of experiments made on myself at various pressures and varying intervals. The electrodes were brass wire 0·25 inches diameter, 5 inches long, and the shock taken from hand to hand. I pointed out that it was "necessary to distinguish between an 'instantaneous' and 'time' shock. . . . . In the former case, there is an instantaneous nervous and muscular contraction causing a feeling as of a blow struck on the inside of the heart. In the latter case, there is a sequence of sensations depending on the voltage and time.

"TABLE I.

Pressure in Volts.	Time interval in Minutes.															
	1.	4	6.	7.	8.	9.	10.	11.	13.	15.	17.	18.	19.	20.	21.	22.
50	—	—	—	VS	VS	VS	VS	S	S	S	S	S	S	S	S	S
100	—	—	VS	VS	VS	VS	S	S	S	S	S	S	S	X	X	X
200	VS	VS	VS	VS	S	S	S	S	S	S	X	X	X	X	X	X^2
300	VS	S	S	S	S	S	X	X	X	X^2	X^2	X^2	X^2	X3	X3	X3
400	S	S	S	X	X	X	X	X^2	X^2	X^2	X3	X3	X3	X4	X4	X4
500	X	X	X	X	X^2	X^2	X^2	X3	X3	X4	X4	X5	—	—	—	—

"REFERENCES: VS is very slight muscular cramp, in reality little more than a tingling sensation; S, slight muscular cramp; X, slight muscular cramp, and a feeling of successive light sharp taps on the inside of the heart; X^2, slight muscular cramp, taps ceased, a slight oppression in the region of the heart; X3, muscular cramp appeared less, but without any appreciable relaxation, oppression in the region of the heart increased; X4, oppression in the region of the heart increased to a painful extent, and a feeling of nausea, resembling that of a slight brain-concussion; and X5, a contented numbed sensation, probably the immediate forerunner of unconsciousness (safe time-limit).

[1] "When the chest is traversed by a certain number of amperes or fraction of an ampere, for a sufficient length of time, the most important effect produced is the immediate cessation of the co-ordinate beat of the heart; consequently the circulation of the blood throughout the body ceases, and the various delicate nerve-cells of the central nervous system die rapidly from the lack of indispensable blood. The action of the current upon the heart is clearly a physiological one, and the state produced in it is what physiologists term 'fibrillation.' Roughly speaking, in this condition the rhythmical synchronism of the contractions of the little muscle-bundles of which the heart is composed is profoundly disturbed, and the contractions

Mr. de Grave.

"It cannot be denied that even a small voltage, such as 50, will, cause stoppage of the heart's action if kept on long enough; this 'time,' for any given voltage, may be called the 'time-limit'; but for the purposes of this paper the 'safe time-limit' is taken; that is to say, the length of time during which an individual can receive a shock of a given voltage without permanent appreciable injury to the system. As this safe time-limit is a most important point, and, moreover, one which can only be settled by actual experiment, the author has made experiments on himself at irregular intervals. The voltages employed, as shown in Table I., were progressive, and for this reason, in addition to the 'subject' being somewhat inured to shocks, the safe time-limit is probably higher by at least 25 per cent. than most people could stand."

Simultaneously with these tests, I made similar tests with alternating currents, 60 periods, both single- and three-phase, the maximum reached being 250 volts for fifteen minutes, the feeling corresponding to x^3.

My resistance at the time of these experiments was more than double the highest obtained by Mr. Trotter, and this must, of course, be taken into account when discussing, what I consider, the abnormally long periods for which I endured the shocks. "The resistance of the human body varies enormously with the health, and again with the nature of the skin at the time, that is whether dry or moist. The heavy black line in Table I. represents a change in the condition of the skin, when it became clammy; the actual current passing at the time of the tests on the right of the line will, therefore, have been greater."

TABLE II.

	+ to – dry.	To earth dry.	+ to – wet.	To earth wet.
Resistance in Ohms	30,000	150,000	10,000	2,500

Earth, in these experiments, was represented by the following conditions: Wet boots and ground, an earth-plate connection 36 inches from the feet.

As far as my personal experience and observation goes, I can answer the points raised by Mr. Aspinall:—(1) Every one is more or less susceptible. (2) I have no experience. (3) When the muscles are relaxed from fatigue, or the health—that described as "run down," the effect of shock appears much less. (5) On tender flesh, burning increases the effect of shock, but on the harder (the palms of the hand) it produces

of the bundles fall out of phase. Thus the heart fails as a blood-pump, and death quickly ensues, unless the circulation is restored. . . . The higher mammalia practically never recover spontaneously from this condition of fibrillation, but the lower the order of the animal the more likely is it to recover. . . . [He does] not consider that consciousness is lost synchronously with the beginning of the shock, although the period of consciousness may be extremely brief. . . . No reliable data can be given as to the minimum intensity of current necessary to produce cardiac fibrillation in man, adding that probably physiological susceptibility to the current varies. The 110 volts lighting-current seemed capable of electrocuting certain individuals."

a coating similar to scorched horn, which has a very high resistance. (6) A man has been rendered insensible by shock without crying out. No experience of a man speaking after receiving a fatal shock. (The word *fatal* in *this connection* requires carefully defining.) (7) From experiments on myself, alternating most likely to be fatal. Mr. de Grave.

The person of weak intellect belongs to a class *per se* as regards shock, the power of standing which is exemplified by the strength of the electric baths administered in the leading asylums—a strength which would make a "mens sana in corpore sano" feel somewhat uneasy.

The Liverpool accident is a good example of the current being shunted by damp clothing. Mr. Aspinall's discovery—I think I may correctly use the word—that a man asleep is not affected, is most interesting and, to my mind, important, so much so that one is led to think that preconceived ideas as to the effect of shock may be wrong, and that the door is here opened for the settlement of this point.

The instructions for restoring the apparently drowned, issued by the Royal National Lifeboat Institution as a footnote to the "Sylvester" method, distinctly state that on no account should the person be held head downward.

Mr. C. P. DARKE (*communicated*): On the 12th of August, 1897, I took a pass at the Kennington underground railway for the Monument, and was lowered in the lift. On asking where I was to go, I was informed "straight ahead." The platform being badly lighted, I fell on the line, with trains due every four minutes. In attempting to rise I grasped the conductor, and had some 400 volts of electricity playing through me, experiencing the sensation as if a cannon-ball were rushing through me from head to foot, and I lost consciousness, feeling death inevitable. I recovered somewhat on being lifted on the platform by two of the porters, who dressed my wounds at the lavatory, having sustained a severe cut in the forehead, an elbow bared to the bone, and a tendon slightly burnt between thumb and finger, notwithstanding which I experienced no headache nor other inconvenience, and was soon enabled to travel home; and, though now in my eighty-third year, am happily free from rheumatism, to which I was before subject. Possibly, if my heart had been weak, the shock would have killed me. But I am under the impression electricity, *judiciously administered*, is beneficial in acute cases of rheumatism and nervous complaints. Within a very few days of my accident I read in the newspaper that an elderly man had that day fallen on the line, and, failing to be extricated, was run over and killed. Mr. Darke.

Mr. E. H. STARLING (*communicated*): An important practical point in connection with electric shock appears to me that, if a man is glued to the terminals of a constant current, the current should, if possible, be switched off *gradually*. It is quite possible that the shock at break might be more dangerous than the one at make. Mr. Starling.

Mr. J. H. ALEXANDER (*communicated*): I have studied both Medicine and Electrical Engineering, and am therefore interested in the subject under discussion. I agree, with Mr. Aspinall, that some people are very much more susceptible to the influence of an electric current Mr. Alexander.

Mr. Alexander.

than others, perhaps from some constitutional state in the individual, such as a highly developed nervous system, which heightens reflex action and makes the sentient nerves better conductors of impressions to the brain. There is little doubt that, to a certain extent, the same person will differ as to his sensibility to impressions at different times, according to the state of his health or his physiological condition at the time of shock. It would probably be found also that the path taken by the current through the body will have an effect as regards the severity of the shock received. Moisture on the skin will to some extent reduce the chance of burning effects, and efforts to help the person shocked should be redoubled if there be no burning. I agree that immediately the victim is removed from contact with the source from whence he was shocked, before beginning artificial respiration or making rhythmic traction on the tongue, we should invert the body, head downwards, for a few seconds to allow the blood to flow to the head and obviate, to some extent, the anæmia of the brain, and at the same time stimulate the nerve centres, especially the cardiac and respiratory centres, and so make the heart and lungs respond more readily to the stimulus of artificial respiration and Laborde's system, when these methods have been begun.

General Webber, in his paper, quotes Dr. Bleile, Professor of Physiology in Ohio State University, who says, "It would appear, therefore, that death in electric shocks is *entirely due* to the fact that the current produced a contraction of the arteries through an influence on the nervous system, and that this constriction throws in such a mechanical impediment to the flow of the blood as the heart is unable to overcome." I agree with the above statement in part, but think that it does not state the whole truth, and is therefore only partly correct, as the current must act on the heart itself as well as on the arteries. It is difficult for any one who has studied physiology, to understand how it can be possible for the involuntary muscular fibres which form the coats of the arteries and arterioles, in the body, to be acted upon by the current and caused to contract (so that the vessels are narrowed in calibre) by reflex action, set up by the action of the current upon the nervous system, without at the same time the involuntary muscular fibres of the cardiac ventricles (the heart) being affected so that the left ventricle may become rigidly contracted and remain in systole. Should there be any disease or weakness of the heart at the time of shock, the chances of recovery are lessened, but if there has been any destruction or disorganisation of the nerve centres or of the nervous ganglia within the substance of the heart itself, recovery could not take place; but if the heart is in a healthy state at the time of shock, and merely thrown into a state of syncope or failure, then I think, with judicious treatment, the person has a chance of recovery. I have seen it stated somewhere that "death after electric shock may result from 'fibrillation' of the heart," or, in other words, the ventricular fibres do not co-ordinate in movement or act together as they ought to do to cause a complete ventricular contraction, and so propel the blood onwards, but certain bundles of fibres or groups contract, it may be, while other groups do not, and this incomplete

contraction soon terminates in death. The heart of any cold-blooded animal, as for instance the frog, will go on beating for fully a quarter of an hour, or even longer, after removal from the body, although not a drop of blood is passing through the organ. As the heart's action begins to get weaker with longer intervals between the contractions, on applying a slight electrical stimulus the action quickens for a short time, even after the stimulus is removed. As the heart is unconnected with the nervous system of the animal it cannot receive its stimulus from that source to cause it to contract and relax. The energy for this muscular contraction is derived from many small nervous ganglia or nerve centres, situated within the walls of the heart itself. Destroy these ganglia, and the contractions of the frog's heart stop at once. When fibrillation is set up in a person's heart, may this action not be due to greater destruction or paralysis of some of the cardiac centres than others by the action of the current through the sympathetic nervous system, in which case certain bundles of fibres may cease to contract, while other bundles still go on contracting for a short time, till death results? Mr. Alexander.

Mr. Trotter says: "While repairing an arc lamp in a steam washing factory at Bradford, in 1899, a man is said to have been killed by a shock at 225 volts; a fatal accident occurred in Germany with about 300 volts." As such low voltages do not, as a rule, give fatal shocks, may it not be possible that both men were suffering from a certain amount of cardiac weakness at the time of the accident, which would render them much less likely to recover after shock? He does not state whether the current was alternating or continuous, but from the low voltage I suppose it would be the central station three-wire continuous system that is meant. I have no doubt Mr. Trotter is correct in saying that "the resistance of dry cloth is very high," and that dry clothing does afford protection from shock. Certain clothing is well known to be a protective against lightning. The Romans used sealskins for this purpose, and the Emperor Augustus is said always to have worn a sealskin in order to be safe during a thunderstorm. Silk and wool afford more protection than linen. I fear that few people could go through Mr. Trotter's experiences in getting so often shocked with currents of such high voltages as he has done and escape scatheless, or even with their lives. Some people appear less liable to bad effects from high voltages, and among them we must include Mr. Trotter and his son. However, I do not think these experiments with high voltage currents should be repeated too often by the same individual, owing to the fear that if it does nothing else it may set up some form of disease, owing to over-stimulation of the central nervous system and the spinal cord. I think Mr. Trotter makes too light of the danger from a fallen trolley wire in the street when he says "there is no danger to any one who may come in contact with it on a frosty day, even if he stands on the rails." This is all very well for a young robust electrician or a strong muscular workman to do in safety, though I believe many will get shocked or burned. What about children, ladies, old people, and delicate persons, especially those with weak hearts? It seems to me that the danger to these is certainly not to be ignored. In great cities,

Mr Alexander.

such as London, Paris, Vienna, New York, Budapest, etc., they have done right in excluding the trolley-wire system. Why should the same thing not be done in Britain, adopting the conduit system, even though it should cost more money per mile of track, if it secures safety to the citizens by so doing? Having just the other day read Mr. Field's contribution to the discussion on the above papers (in the technical press) I quite agree with him that, in many cases, when a medical man is hastily called upon, in the event of an accident having taken place, he may not be provided with the necessary hypodermic syringe and subcutaneous injections required; and, to meet this emergency, all high-tension sub-stations and generating stations, as he proposes, should be provided with a small scaled case containing all that it is necessary to use in these instances. I should suppose that any intelligent electrician or engineer, after being shown the method, would be quite capable of administering a hypodermic injection of ether, etc., to any one who had met with an accidental shock in the generating station or even outside, and in this way be the means of saving a life. Why should the medical profession object to an unqualified person giving a subcutaneous injection in an emergency? There is no danger if the solution be injected not into but *under* the skin, into the subcutaneous cellular tissue on the outside of an arm or leg, and if care is taken to avoid the veins. It might equally well be argued that no unqualified person should be allowed, in the event of a severe accident, to apply pressure or a tourniquet to a limb to arrest hæmorrhage, or even to administer a restorative. Why should not the administration of a hypodermic injection of ether or other drug, given for shocks, be part of the duty of a trained ambulance electrical engineer or other responsible person working in a generating station? With hypodermic tabloids, containing the exact number of grains or minims of the solution, there could be no mistake made with regard to the dose administered, and if a larger dose was required than that given, the extra could be injected by the doctor on arrival. When a person has been shocked and has lost consciousness, besides immediately beginning artificial respiration, I would be inclined to advise an injection of nitro-glycerine or of nitrite of amyl, given subcutaneously, as both of these drugs have the power of relaxing the spasmodic contraction of the arteries and arterioles which occurs in Bright's disease with great difficulty of breathing and give relief; and why should they not act in a similar manner after electric shock, and so lessen the work of the heart in forcing the blood through the partially dilated vessels, from what it would be if the vessels were greatly contracted in calibre? I will conclude by suggesting that any one who intends to become an electrical engineer should first undergo a medical examination, and that if he show signs of cardiac weakness, as such a condition is sometimes apt to get worse, he should be rejected by the medical man and advised to follow some other profession, where there is no chance of his getting an electric shock from handling apparatus charged to a high potential such as exists in a generating station. In addition, I believe that high-pressure currents may possibly affect the blood itself, as in fatal cases after lightning stroke the blood is sometimes found coagulated in the veins.

Mr. ROBERT S. DOBBIE (*communicated*): In relation to the very instructive papers by Major-General Webber, Mr. Aspinall, and Mr. Trotter, that have lately been presented to us, I have a few cases in my experience that may be of interest. Mr. Dobbie.

A linesman who was very drunk, had his attention drawn to a lamp in the station which was wrongly connected (the bottom carbon being positive), and attempted to set it right; the lamp was suspended from a board containing a short-circuiting switch which he supposed he had closed, but it seems that he only shook the lamp so that the carbons crossed, the switch being left open; he then proceeded to take out the wires from the terminals of the lamp, thus opening the circuit which was that of a 30-light Thomson-Houston machine (current equals 9·6 amperes, the E.M.F. being at least 1,400 volts at terminals). The wire leading into the lamp terminal was of the sort known as "Underwriters"; one of his hands was grasping this, and the other the frame of the lamp, which was not insulated; he was instantly knocked down, thereby breaking away the wire from the boards, and rendered insensible, in which state he remained some ten minutes, his breathing was laboured, but I instituted the treatment prescribed in cases of drowning, and also applied ice down his back; we then got him up, and although a little shaky, he was able to walk home without assistance about half an hour after recovering consciousness, and it was noticed that he was perfectly sober. One of his hands was severely burnt, the other very slightly so, and beyond the inconvenience of these burns he did not suffer any after-effects.

I received a shock under different conditions from a similar machine by touching a lamp while standing upon the slightly damp road. The line had been earthed at such a point that there was a pressure of about 750 volts. I was knocked down, and the sensation was as if I had received a severe blow that had struck my legs from under me. I was dazed, I can hardly say insensible, for a few seconds, and sitting up, it seemed that my legs were without feeling, and, in fact, I felt them with my hands to feel if they were there, so to speak; I then experienced a tingling sensation in them similar to that which is known as "pins and needles," which gradually passed away. I was unable to rise or move my legs for about half a minute; but when I did so, being assisted, power and feeling rapidly returned, and at about the end of ten minutes I was all right. There was a slight burn on the hand—a small area of about a quarter of an inch in diameter but deep—leaving a slight scar.

The variable susceptibility of different persons is well known, but I have come across a man who is more easily affected than any one I ever heard of; he could not stand the sensation produced by an 80-volt machine, although, being a fitter, his hands were in a horny condition, and they did not seem to be abnormally moist. I have never taken his resistance or seen him receive a shock from more than 80 volts, but the effect of this seemed to be quite as much as he could stand.

Mr. ALEX. P. TROTTER, in reply: With regard to the question by Dr. Hedley as to how far my experiments really represent working conditions, the only physical difference between a given current in Mr. Trotter.

Mr. Trotter. milliamperes from a battery or from a dynamo is that the former is perfectly steady, while the latter may be slightly fluctuating. A battery current is therefore the least painful, and the current from an Evershed ohm-meter——

Mr. Evershed. Mr. S. EVERSHED: My ohm-meter does not give any current at all!

Mr. Trotter. Mr. ALEX. P. TROTTER: Well, the current from the admirable generator which Mr. Evershed gives away with his ohm-meter is distinctly more painful. All my experiments, until to-night, have been made upon the 500-volt conductors of large tramway systems, or with 400 volts from the Westminster Company, in series with 100 volts from accumulators at the Board of Trade Electrical Standards Laboratory, these accumulators being rated at an output of 25 amperes. I can detect no difference in the sensation produced by a current from the battery I am using to-night, and the sensation produced by the same number of milliamperes from a dynamo. Out of 80 persons experimented upon, 33 took the current from the battery after the meeting, and 47 the current from the dynamos, and I find no difference between the results. In the case of a battery I do not, as Dr. Hedley suggests, take into account the capacity or internal resistance, nor in the case of a dynamo the kinetic energy or the self-induction. The only quantity I am concerned with is the current in milliamperes. It is true that the internal resistance of the battery might affect the current, but under the conditions of my experiments the skin resistance is so great that the internal resistance of the battery is insignificant. I did not measure the internal resistance of the battery; I was satisfied to find that 25 lamps, taking altogether about 1 ampere, were brightly lighted. The volts must have been more than 450, and therefore the internal resistance could not have been as much as 50 ohms. If that had been the resistance, it would have made a difference of one part in a thousand in the case of a 10-milliampere current—that is to say, under the conditions when a dynamo would give 10 milliamperes, the battery would give 9·99 milliamperes, the conditions for a 10-milliampere current at 500 volts being a resistance of 50,000 ohms.

Mr. M. B. Field, agreeing with me generally, makes an important *misquotation* from my paper. I wrote: "Neither the man in the street, nor the man on a car, runs any risk of taking 500 volts skin to metal." Mr. Field accidentally reads "risk in taking" instead of "risk of taking." I quite agree that, *if* he takes it, the result would be serious; I go farther, and say that *then* it is no question at all of risk, but of positive danger. My point was that "the man in the street"—that is, an ordinary member of the public—runs no such risk; he may get shocks, and the whole object of my paper is to discuss the conditions of such shocks. That linesmen may stand on a handrail and be unable to leave hold of a trolley wire is an important example of quite another class of shocks, namely, those to which linesmen and other workers are liable. But my paper does not deal with those. The object of my paper has been greatly misunderstood, but it is clearly expressed in the "Conclusion":—"The conditions under which serious shocks *are not produced* by 500 volts are discussed in the paper, and it is safe to assume that all shocks more serious than those which are recorded, are

dangerous." I claim that my investigations have shown that the conditions under which serious shocks are not produced by 500 volts are more numerous than was generally known. Mr. Field's other observations are most instructive. Mr. Trotter.

It is unfortunate that Mr. L. W. De Grave's results were not given in milliamperes, instead of volts and the vague statement that his resistance was double the highest obtained by me. I am quite unable to understand how, with electrodes ¼ in. in diameter and 5 in. long, he could take 300, 400, 500, or even 200 volts hand to hand for as many seconds as he gives minutes. The omission is doubly unfortunate, for the results would have been most valuable, and Mr. De Grave's fortitude in making the experiments must be admired even if his wisdom in risking danger cannot be commended.

I do not agree that wet clothing shunted the current in the case of the Liverpool accident, but it rather acted as a main conductor. It is difficult to account for the shocks in this case, if the victims were really enwrapped in the wires.

Mr. C. P. Darke's serious accident, involving, as it did, a severe cut on the forehead, an elbow bared to the bone, the grasping of the conductor, and losing consciousness and lying until picked up, confirms the following passage in my paper: "It is very desirable that the live rails of third-rail railways should be guarded by planks to prevent short-circuits by tools, etc., and to make it less easy for a person falling on the rails to make contact with bare skin. While experience has shown that a person so falling may receive a serious and even fatal shock, this can only occur if he make contact with both a live rail and a running rail with bare skin, or thoroughly wetted clothes, and if he lie there for a time." Mr. Darke's escape, on which he is to be congratulated, shows that I have overestimated rather than underestimated the dangers of 500 volts.

Mr. J. H. Alexander writes of my supposed "experiences in getting so often shocked with currents of such high voltages" and escaping scatheless or even with my life. I have not yet alluded to any such experiences, for they were beyond the limit of my paper, but I may take this opportunity of stating that my experiences of serious shock are very similar to those of Mr. Sayers. Mr. Alexander alludes to what a young robust electrician or a muscular workman may do in safety, and refers to my son, who does not come within even the first of these categories, and to "children, ladies, old people, and delicate persons, especially those with weak hearts. "It seems," he adds, "that the danger to these is certainly not to be ignored." But, in reply, I point to my experiments on eighty persons, including twelve women and six children. What they felt, I do not know. What they said they felt, I know. On the record sheets I left a column for "Remarks," and these I have suppressed, not because they were unfit for publication, but because they were uninteresting. What they took in milliamperes I have recorded, and these records may be compared with the description of sensations given in the paragraph of my paper headed *Physiological and Electrical.*

While my paper was very limited in its scope, I do not think that it

Mr. Trotter. can be said to throw dust in the eyes of the public. If I had dwelt on the conditions under which shocks *may* be dangerous, such as the grasping and inability to let go, contact with the flesh through broken skin, the question of the watts dissipated instead of mere milliamperes, the paper might have been five times as long, and certainly would not have had one-fifth of the readers.

I have, in conclusion, to express my thanks to Mr. J. Rennie and to Mr. W. St. J. Miller, of the Electrical Standards Laboratory of the Board of Trade, for their untiring assistance in the tests and experiments.

Mr. Aspinall. Mr. F. B. Aspinall, in reply (*communicated, April* 16, 1902): I must thank the medical profession for the kind way in which they have received my paper, and I am sure the information they have given us has been most instructive.

It is impossible for me, as an engineer, to do justice to every speaker, but I think we can learn some valuable facts. For instance, it seems quite clear that the resistance of the human body depends entirely on the area of contact, and that the severity of a shock depends upon this and upon the time during which the body is in circuit.

To my mind, the practical lesson to be learnt s to make all live metal of such a shape that it cannot be grasped with the hands, as the danger lies in getting the hands closed round the metal and not being able to release oneself. For instance, is the centre rail always of the best shape? If the metal can be insulated, or if the poles can be kept so far apart that both cannot be touched simultaneously, this does not apply. It also seems quite clear that there are a large number of people in the world who would be killed by any kind of shock, electrical or otherwise, and it is hardly fair to put all the blame on electricity if they should be fatally injured.

Dr. Hedley seems to think that we are making too light of shocks, from the point of view of the public; but I think from the point of view of the public safety it is best to do so, as, although I have made careful inquiries, I can find no case of an electrical employé being killed by a shock of under 500 volts. Surely this seems to show that fright has a lot to do with deaths at low voltage.

For instance, what would happen to a man afraid of electricity if he got hung up like Mr. Field? I have personally known a man held by 100 volts, due to his hands contracting around metal. He used terribly bad language, but could not get away. Personally, I am convinced that my opinion is correct that under 500 volts something abnormal must happen if death occurs. I am not prepared to touch 500 volts with the bare skin, as I know 400 volts is very unpleasant; but I know of an extremely large number of cases where nothing happened when 400 to 500 volt shocks were received to the bare skin, but it must be distinctly understood that the person receiving them did not get hung up.

As regards the actual cause of death in cases of a true electric death, it seems pretty safe to say that the heart or lungs fail, but how they are affected is not thoroughly understood. Dr. Lewis Jones, I think, puts the case most clearly when he says if a man is dead you

can do nothing; but as it is impossible to be quite certain, you must try to stimulate the heart and lungs. It therefore seems to me you can do two things in the order stated:— Mr. Aspinall.

1. Stimulate the heart by a sharp blow on chest over heart, and by lowering the body as suggested by me.

2. Stimulate the lungs by Sylvester's and Laborde's methods.

Do the first once, and continue the second for an hour. If at the end of this time no signs of life appear, you can feel you have done all you can, and that death has really occurred.

In conclusion, I should much like to discuss the medical aspect of the case, but I feel it would be presumptuous on my part to do so.

Maj.-Gen. Webber.

Major-General WEBBER (*in reply*)[1]: I think that the Journal will contain a unique collection of almost all that is up to date worth knowing on the subject under discussion.

As regards the criticism of my preliminary contention, namely, that the heart is not "a pump" in the sense of being a single source of pressure at the centre of a system of hydraulic supply, which Dr. Hedley refers to as a "doubt thrown on the first principles of physiology," and Dr. Lewis Jones refers to as a "heresy," I shall be content to leave the suggestion to ferment in the minds of those who have taken the trouble to give careful thought to the subject independently of text-book teaching. Dr. Hedley's explanation, that the measure of the pressure, in the usual manner, namely by a gauge in a cannula inserted into the carotid artery, is a measure of the contracting force of the heart being the pressure of the discharge from the ventricle as against the peripheral resistance of the circulating system, is faultless; but he overlooks that it in no way negatives my suggestion, that the total actual resistance may be kept down by, say, a "booster" of one form or another, or even by a unit of storage placed in or at each capillary.

If my suggestion was startling, it was to awaken my audience to evidence against a dogma, which careful thought, as to the complex calculations necessary to compute the resistance to heart pressure, shows to exist. At any rate I think that I have quoted useful matter to show that my theory as to the extension of the effects of shock over a large area, if not all, of the skin surface, whereby every cutaneous capillary is attacked, has some foundation.

Our members should not forget that in France there is a Marey Institute devoted to such a subject as this.

To read at our last meeting, had time allowed, I had, hearing of Dr. Margaret Cleaves' absence, prepared some remarks on the work of Prévost and Batelli and of Cunningham, to which Dr. Hedley referred.

We must express our indebtedness to Dr. Margaret Cleaves for her painstaking articles in the *Electrical Review* of the 29th of November 6th and 27th of December, 1901, and on the 10th of January and the 21st and 29th of February, 1902. I have to thank the Editors for having courteously drawn my attention to these valuable articles, which

[1] This reply was given and the ensuing vote of thanks was passed at the meeting on March 20th, but is reported here in order to complete the record of the discussion on Electrical Shocks in Part 156 of the Journal.

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commenced to appear after my paper had been completed and, through no fault of theirs, escaped my notice. They repair my omission in not having referred to the work of Prévost and Batelli of Zurich, and to that of Professor R. H. Cunningham. The chief interest they have, as bearing on the propositions I have set forth, are the prominence they give to the heart as being the "most vulnerable organ," and that in the heart, when "included in the circuit," what are called "fibrillary," as contrasted with natural, contractions are produced. In the many experiments on animals, accidents from industrial currents, effects of lighting, etc., this symptom is diagnosed. Paralysis of the heart appears to have been the object of the experiments of the above-named physiologists. Prévost and Batelli came to the conclusion that low-pressure currents produce paralysis of the heart by converting the natural pulsation into ventricular tremulation, and that this does not occur when high-pressure currents are used, ultimate death being due to "Inhibition of the respiration." They also observed as the alternative result of their investigations, that *if* the heart does not lie in its path, this fibrillary tremor is likewise produced by high-pressure current, and that, violent excitations of the heart by a make and break, or alternating current, can cause the cessation of the fibrillary tremor to cease and the resumption of healthy conditions.

In such a case, if asphyxia has taken place, respiration *can* be artificially restored; in other words natural pulsations can, by the electric current, be made to replace the fibrillary tremulations, which would otherwise end in paralysis and death.

But it is when Dr. Margaret Cleaves deals with Professor Cunningham's researches, that one finds an opening to give some reason in favour of the theory I have propounded, namely, that in a healthy man, in whom the vital forces are not depressed, and whose skin is resistant except *viâ* the pores, paralysis of the circulation in the periphery of its system takes place. And I would go to-night one step further, with the light I have gathered with the assistance of Dr. Margaret Cleaves, and venture to suggest that as a consequence of the rapid distribution of a high-pressure current over the surface of the body, transformation into a low-pressure one at some instant of its passage *viâ* the pores takes place. The immediate symptom, namely, the "cessation of the co-ordinate rhythmical movements of the heart, and their disappearance into tremulations," may thus be communicated from the cutaneous capillaries, quite as well as by the means used by Cunningham in his experiments. Remember, that the experimenter adopts naturally the best means to secure the result of the test which he has planned. In this case he made the best contacts he could over the chest for the negative electrode by first removing the hair, and over the skull by "dissecting off the soft parts which cover it," for the attachment of the positive pole.[1] These preparations, made to secure the passage of the dose by a particular path through the body, namely, *viâ* the heart, would never exist in the healthy subject. In the carotid artery of the

[1] Mr. M. B. Field's "communication" *re* the danger of contacts where "the skin has been cut," which I have seen since the meeting, bears on this aspect of the question.

"dog" (which was the subject of an important experiment), a *cannula* was inserted to measure the blood-pressure, a form of measurement of the muscular strength of the walls of the heart used for a century which I have claimed to be inconclusive of that strength. The final result with a pressure of 116 volts, and a current of 0·4 ampere, after a closure of 76 seconds, as might have been anticipated, was that the blood-pressure rapidly fell to zero. The tracings taken showed an "almost total extinction of the arterial circulation." Cunningham's belief "that there is no question of the instantaneous death of the muscle cells of the heart" under the conditions of *his* experiment, carefully prepared and carried out to effect that object, is no doubt fully justified. Maj.-Gen. Webber.

There are also accounts of the action of a dose, when directly applied to the brain, in which proof is claimed, that the mode of death is *quite different* from that which takes place when the heart lies in the conducting path. Curiously enough the blood-pressure during such an experiment went up twice or thrice its ordinary height. Lastly, my suggestions receive some support, I think, from one of Cunningham's own conclusions, namely, that "strong electrical currents applied to the surface of the skin affect the heart in the same manner as currents of less strength do when they are applied directly to the exposed heart." I cannot do better than hope that the writer of these articles will allow herself to be the abstracter for our publication known as *Science Abstracts* of all that appears in the future on this subject, which so vitally affects that wonderful circulation, the movement of which never ceases between the moment of our birth and our death.

To Dr. Legge and Mr. Fearon the Institution is indebted for their practical remarks on the subject. Their presence, it may be hoped, indicates a *rapprochement* between the Inspector and the Inspected, which will conduce to the smooth working in the future of Clause 45 of the Factory Act of 1901.

Yesterday the appointment of one of our members, Mr. Gilbert S. Ram, to be Electrical Inspector of Factories and Workshops was announced. I think that your Council's strenuous action in this question has not been without result.

To Dr. Legge I would remark that asphyxia is a *secondary* result of stoppage of the circulation, and that I hope he will allow me to claim as my own one—the last of his four views. I regret I had overlooked the recommendation of Mr. Cottrell referred to by him.

Mr. Fearon has so far mistaken one object of my paper, as to suggest that it makes objection to inspection, because it tries to show the inconsistency of the terms of Clause 45 of the Act, with complete and efficient inspection.[1] For instance, it includes generating and transforming stations in which, as Mr. Sayers pointed out, a very few skilled men are employed, where accidents are very rare, while it omits all other portions of systems of distribution, to the maintenance of

[1] Mr. Henry Hall, in a "communication" which I have seen since the meeting, wrongly assumes that I object to inspection. The Institution's objection was to the inclusion of electrical generating and transforming stations in the Factory Acts as non-textile factories.

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which almost all the accidents of the past twenty years are traceable. Only if he can prove the employé has to be protected against the parsimony of the "capitalist" and of the "consulting engineer," in the industry with which we are connected, has he a good case. Mr. Fearon pointed out that high-pressure stations alone are affected, but practically almost all stations, both generating and transforming, are included under that Board of Trade distinction. He says there is no difficulty in designing new switchboards to fulfil the conditions in Clauses III. and VI. of the rules suggested by the Tennent Committee, but what about having to "scrap" all the old boards? He admits the difficulty of protecting all rings and commutators. One of my contentions was that what is known as "Factory Inspection" is not suited to the industry, not that inspection is unnecessary.

Mr. Joyce and Mr. Sayers asked questions, which to my mind (having the subject for many years under observation) are of the greatest interest, and deserve the careful investigation of the thoughtful student.

Dr. Lewis Jones's remarks on the subject of "pain" and of the "cry" mentioned by Mr. Aspinall, made me long to offer him a solution of action and reaction in nerve work, which the question has often instigated me to express in non-technical language. Of the remarks of Dr. McClure, that part which will most interest electricians, is as to the varying dielectric conditions of the various tissues of mammalia, both when alive and dead.

The following was written at the same time as the first part of my paper, which was read on the 27th of February, 1902, and is referred to in the first page of the same.

The difference of the situation between the date—1897—of these proposed regulations and now, is that what was then a matter of recommendation to the industry, can now, by the passage of the Bill of 1901, be legally enforced by any Factory Inspector, and that, under heavy penalty by a magistrate, any electrical generating and transforming works (transforming having since been added) whether existing under statutory obligations to maintain a constant supply or not, can be shut down and stopped running without appeal.

The supervision of and legislation for a large portion, if not the whole of the electrical industry with which the members of our Institution are intimately connected, has been transferred from the Board of Trade to the Home Office, and the generation, and transformation (which is a stage in the process of distribution), has been classified as amongst the dangerous trades.

It might have been held, that, in what might be called the youth of an industry, the exceptionally small number of accidents by shock that had happened *in these kingdoms* before the Report in 1897 would have told against the need for this kind of legislation.

An examination of the published records of accidents causing death by electric shock in the period 1880 to 1890 inclusive shows that in the whole world thirty-eight persons lost their lives in eleven years.

Of these only two occurred within a generating station, and one of these two was the well-known case in 1884 at the Health Exhibition with a Hochausen dynamo, on which Mr. Trotter reported at the time. Maj.-Gen. Webber.

Thirty-six of these accidents were in connection with overhead lines, thirty-four *outside* these kingdoms. The majority were on lines of which the construction would never have been agreed to by engineers belonging to this Institution, and (I believe) is now abandoned in other countries.

My audience will here observe that only two out of thirty-eight of these accidents took place on plant which the late Factory Acts has brought under Home Office inspection.

In the seven-year period from 1892 to 1898 inclusive, there were nineteen accidents in the United Kingdom. Twelve of these only occurred at places which would have been, under the Act of 1901, subject to Factory Inspection, and of these twelve, eight were cases in which the simple personal wilful carelessness of expert employés gave rise to the accident, and which all the grandmotherly precautions in the world would not have prevented.

In 1899, 19,616 accidents of all kinds to males in these kingdoms are reported. And yet in the Northampton District the Inspector reports no accidents under the heading electric shock. In the Southern Inspection Division there was one case of accident at a switchboard, which caused the death of a skilled man thoroughly acquainted with the board, having fitted it up himself. At the inquest the proprietor (it was a private business installation) was found to have been negligent in not having provided sufficient insulation for the floor, *i.e.*, where the man stood, the man having accidentally touched a high tension switch. The Inspector of the Midland Division had no accidents to report. The Walsall Inspector reported two "harmless shocks" by using uninsulated spanners. The Inspector of South Wales reported "a few harmless shocks."

The Inspector of the Midland district prosecuted the Bilston Urban District Council, and tried to prove that electricity is an "article of commerce," and that "it was generated by way of trade" and for "purposes of gain," as generated by the Council for lighting the Market Hall. The magistrate gave his reason for considering electricity to be even then an article within the meaning of the Act. He considered that it was (in lighting the Hall) "prepared for gain," and therefore did not see any reason why the works should not come within the meaning of the Factory and Workshops Act. A penalty was imposed for not having fixed at the works an Abstract of the Act. An appeal would probably have upset the decision, but there was none. No one cared to look forward.

In the North-Western Division an accident in the Bolton Corporation Electricity Department by which two men lost their lives is reported. In this case the shock received by the men was from having made a mistake in the switch they used while at work in moving a transformer. This case is an instance in which no precautions arising out of inspection could have prevented the accident.

In the report of the Medical Inspector not one case of electric shock is mentioned.

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The other associated bodies which were in a position to take up the subject when legislation became imminent were, the Electrical Section of the London Chamber of Commerce, and the Tramways and Light Railways Association. It appears (my informant is Mr. Garcke) that a joint committee of these bodies had "been considering the matter," and had "decided to take no action." I suppose the Association expected that *their* premises would escape inspection. However, the Electrical Section of the Chamber of Commerce had the subject brought under its notice by the Manufacturers' Section of the Chamber, and a committee of twenty-four, representing all the industries affected by the Bill, was appointed on April 12, 1901, on which Mr. Percy Sellon (the chairman of the Electrical Section) and the writer represented the electrical trades. This committee naturally dealt with the whole Bill, so that Clause No. 45, which affected the electrical industry, had the exclusive attention of only the two electrical engineers whom I have named. When the Joint Committee of the Chamber of Commerce and of the Light Railways Association met, as above stated, either they failed to realise the importance of the question, or they missed an opportunity of associating themselves with this Institution to bring about a joint action which might have given better results. The only other body which (so far as I can ascertain) moved in the matter was an Association of Chairmen of the London Electric Supply Companies, who, through Mr. H. B. Cripps, on the 10th of July addressed the Board of Trade on the subject.

To the Chamber of Commerce belongs whatever credit there is of moving first on the questions raised by the whole of the Bill, but in June our Institution, as I have previously stated, took up the special question identified with Clause 45.

Early in June I conducted a member of the Grand Committee of the House of Commons on Trade on a visit to transforming stations in London, so that he might appreciate the circumstances of the premises for which it was proposed to legislate. At the same time transforming stations with accumulators were shown to him, because some members of the Parliamentary Committee, having heard that there is danger in connection with the manufacture of accumulators, had construed this into a probable danger to the attendant in a transforming station from their presence while "gassing" is going on!

Broadly speaking the Home Secretary stood between the two parties, namely, those who wanted to include in the Bill everything, however remotely in accordance with the extreme spirit of Factory legislation, and those who, subject to their loyalty to the Government, would help to exclude anything that did not accord with their peculiar sentiment on the subject of some particular trade.

If the subject had been discussed at all by the Grand Committee, which it was not, the case for the industry might have been stated as follows:—

That transforming places must be largely used, and that their number is at present, and will eventually be, many times greater than that of generating stations.

That the Board of Trade Regulations under which the supply of

electricity is authorised has already specially provided for the protection of those whose duty it is to deal with this class of electrical apparatus, whether it is stationary or in motion, and afford all necessary protection. Maj.-Gen. Webber.

That no precautions (beyond those which the undertakers for absolute self-protection must take) can prevent accidents from an invisible danger, due to carelessness or rashness; and therefore, that while inspection will in one direction tend to exonerate undertakers, it will in the other impose upon the user possibly unnecessary and restrictive precautions.

That the law under the previous Factory Acts did not cover anything analogous to the *transformation* of electrical energy; that there is no manual labour engaged in a manufacturing sense in a transformation station; that the continuous presence of an attendant or of an operative is not imperative, and in by far the majority of transformers used is quite unnecessary.

That it was straining the meaning of the word "machinery" as employed under the terms of the previous Acts to apply it to apparatus which in many transforming stations is not in motion.

That in other industries the alteration of pressure in systems of distribution, such as hydraulic energy, coal-gas, etc., where water at high pressure is to be adapted for use, and gas is to be adapted for heating, or carburetted for increased lighting, inspection is not insisted on, although the transformation is effected in places in which there would be danger to an unskilled person.

The propriety of adding words in some such form as the following, viz., in Clause 45 after the word "transformed," might have been suggested:—

"In a place in which moving mechanism and in which unskilled labour are both in use."

It might further have been advanced for consideration that the evidence taken by the Committee on Dangerous Trades might be considered in two ways, viz.:—

(1) That cases in which it has been shown that injury has been received, or even lost by contact with an invisible danger, were examples which are common to the infancy of all great undertakings for the utilisation of the forces of Nature, and that history had shown that, as time went on, the precautions incumbent on engineers to protect trained and skilled labour had been adopted without the intervention of State aid.

(2) That seeing the possible enormous proportions to which the industries associated with electrical distribution are likely to assume in the immediate future, it might be wise, in view of the great interests which may be involved, and the fact that all electrical works are carried out subject to Board of Trade regulations, that everything connected with the electrical industry were removed from factory inspection, thereby throwing the entire responsibility on the undertaker, and thus

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> avoiding all possibility of friction or impediment in the progress of so valuable an industry.
>
> Lastly, it might have been pointed out that the establishment of continual inspection by properly qualified inspectors, to be effective, must involve the country in a considerable increase in the present expenditure on factory inspection; whereas, if real practical special inspection by qualified experts, as takes place before a line of railway is opened, was, in future, to be the duty of the Board of Trade, the necessary fees might be made repayable by the undertakers.

On the 18th of July, when the Committee came to discuss Clause 45, it divided on a motion to leave out the whole of the clause which referred to electrical generating and transforming stations. It was defeated by 28 against 6. This division was taken without any discussion in Committee *whatever* as to the real merits of the case. And unfortunately (as is always in the case of Grand Committee, I believe) no evidence was taken.

At a subsequent meeting it is understood that the Home Secretary gave the mover a promise to "give the matter consideration," as to the question of the "inclusion of transforming stations," but on this occasion the latter Member reached the Committee Room too late, so that the case as regards transformer stations was never stated or discussed in Committee.

On the report stage in Committee another Member moved an amendment to exempt "premises where the number of persons employed in generating or transforming electrical energy did not exceed four." To this the Home Secretary is reported to have promised "to introduce words that would meet the case."

In this latter case the object was to exclude (what we should call) private installations, but it is very probable, when it was shown, that if applied to transforming stations it would practically exclude all of that nature; the words which would have recognised part of what this Institution was contending for were not introduced.

As amended by the Standing Committee on Trades on the 29th July and reported to the House of Commons, the clause was worded thus:—

> "Electrical Stations, that is to say any premises, or any part of any premises, in which electrical energy is generated or transformed, either for the purpose of supply by way of trade, or for any purpose incidental to any other business, except the transmission of signals or messages.

On the 13th and 14th of August the Bill as so amended was considered, and when Schedule 6 was reached a Member pointed out that although an electrical installation in a private house would not, one in a bank or counting house would, come under the terms of the Act. To this the Home Secretary is said to have given an assurance to the contrary, and to have promised to introduce words to prevent it, which, however, he never did.

The Bill was brought up to the House of Lords from the House of

Commons on August 14, 1901, when the noble Lord representing the Home Office procured the addition of the following words, Maj.-Gen Webber.

> "Or for the lighting of any street, public place, or public building, or of any hotel, or of any railway, mine, or other industrial undertaking."

And thus, whether for good or evil, electrical generating, and, many if not all, transforming, stations, have been placed by law under the incidence of the Factory Acts.

The PRESIDENT: I am sure you will readily accord the authors of these papers a very hearty vote of thanks for the information which they have brought before us, and, in fact, before the world. The subject treated of is one of very great importance from a humanitarian as well as from a scientific point of view. We should all like to know what it is that causes life to be suspended or destroyed by the action of the current. Mr. Aspinall, in one of the instances quoted by him, referred to a man who had received a shock—I do not think he mentioned the voltage, but it was a high voltage apparently—and that during the time the current was passing through his frame he spoke, remarking that he was all right, and immediately afterwards fell down dead. It would appear from this that the shock did not instantly kill the man, otherwise he could not have spoken; so that the passage of this current through him did not destroy that which was vital; it took some time before it did so. Another instance of very great interest to me mentioned by Mr. Aspinall was that in which a man had received a shock—I think of 2,000 volts alternating. He fell down as though dead, and afterwards life was revived by his being up-ended as it were, his head being brought down to about 45° from the horizontal. As Mr. Aspinall had put it, it caused the blood to run to the brain. That suggested to me—I was not here on the last occasion to hear the discussion—whether the treatment which we now follow for the restoration of those who are affected by these shocks is a correct one. I have no doubt that the attention which has been drawn to the subject by these papers, and the discussion which has taken place in this room, will attract attention to the subject, and that we may yet derive further benefit from it with regard to the mode of treatment to which it is desirable to subject those who unfortunately have been subject to electric shock. General Webber has, quite independent of the physiological side of the question which he has treated, and treated in a very admirable manner, drawn attention to the set of regulations prepared apparently for the purpose of forming official Rules to be observed under the recent Factory Act. In referring to those regulations he has done, in my opinion, good yeoman service for the Industry. At the same time we have to bear in mind that those regulations are not adopted, and it is to be hoped that before any regulations whatever are framed that grave consideration will be bestowed upon the effect they may have upon the industry at large. Electricity is undoubtedly the great power-factor of the future, and it will permeate almost every mode of manufacture or locomotion on the earth. It is impossible to say to what extent it will enter into industrial production; at all events it is a fact of so much importance as to call The President.

The President.

for the gravest consideration in relation to any regulations which may be imposed upon the industry that may possibly have a retarding effect. Electrical engineers, of course, are acquainted as well as anybody, probably better than anybody, with the dangers that attend the generation and employment of electricity. Electrical engineers are not inhuman. They do not desire to destroy the lives of those whom they employ. Necessarily they would take all possible precautions for their protection. They would sooner keep a good man about them than they would let him, by his own carelessness, destroy his life, and thus lose his services. Nor must we forget that those who are engaged in the production of electricity have to face the fact that they work under the Employers' Liability Act and the Workmen's Compensation Act. Therefore it is in every way to their interest to protect their employés. All these facts I have no doubt will be apparent to those to whom may be entrusted the duty of drawing up regulations which are to affect the production of electricity. We know that every one is anxious to magnify the importance of his office. An inspector enters your premises; he looks about him and he sees if he can find anything on which he can make a recommendation. He makes his recommendation, and you comply with it. He visits you a second time, when in all probability he finds something more to recommend. This points to the necessity of any regulations that may be adopted in relation to the generation and transformation of electricity being of a very rigid character, that there shall be no latitude for the inspector to go beyond. I venture to hope, and I quite believe, that when these regulations are being formed this Institution may be consulted, and that the regulations may be drafted under the joint guidance of members of this Institution and members of that State Department which will be called upon to administer them.

Gentlemen, I am sorry to have detained you. I am quite sure that you will accord a very hearty vote of thanks to General Webber, Mr. Aspinall, and Mr. Trotter for their very interesting and instructive papers.

The vote was carried by acclamation.

The CHAIRMAN announced that the scrutineers reported the following candidates to have been duly elected:—

As Member:

Frank Barnes Spencer.

As Associate Members:

Daniel Adamson.
Frederick Wm. Allen.
Robert Harry Campion.
Arthur W. Hine.

As Associates:

F. P. Aulton.
Robert John Boyd.
Ernest Albert Buxton.
Robert Lowe.
Herbert C. Gordon Oakshott.
Nathaniel Marion Snyder.
Harry E. Steel.
Geo. Nevil Thomas.
Wm. Sansome Tucker.

As Students :

Joseph Allen.
John Wm. Bell.
Randal S. Callander.
Guy N. Cheesman.
Walter John Cridge.
John George Cundy, Jun.
Harold Wm. S. Davey.
Norman Dyer Field.
Ernest Wm. P. Fulcher.
Edgar Hoyle.
J. W. Jacques.
Louis Lehuraux.
Arthur Nield.
Wm. Godfrey Thomas Pope.
Armstrong G. Robinson.
Jose M. Saenz.
Harding B. Simons.
Ernest Stubbs.
Walter C. L. Vickers.
Wm. H. B. Wight.

CAPE TOWN LOCAL SECTION.

SOME NOTES ON ELECTRICAL ENGINEERING PRACTICE IN EUROPE AND AMERICA.

By JOHN DENHAM, Member.

(*Read at Meeting of Section, December 2, 1901.*)

At very short notice I have been asked to furnish a paper to be read before this Local Section, dealing with electrical matters which I came across during my recent tour through Europe and America.

The plant installed at Shepherd's Bush for the Central London Railway is made by the General Electric Company of America. It consists of six 3-phase generators, each of 850 k.w. 5,000 volts, 25 periods, driven by Allis cross compound engines with Corliss gear, speed 95 revolutions. Considerable difficulty has been found in running these sets in parallel and it is not usually done. Three-core cables convey the high-tension current to different substations, where it is transformed down by 300 k.w. air-cooled transformers to 330 volts, and works rotary converters of 900 k.w., running at 250 revolutions and giving 500 to 550 volts on the direct-current side. The section of line nearest the station is fed from rotaries located in the power station. The rotaries work well and are very small for their output.

Many of the London Lighting Stations are changing over from 220 volt 3-wire system to the 440 volt, and as they are using the original cables, there are numerous serious breakdowns constantly happening. The tendency now is to build high-tension polyphase generating stations on the outskirts of London, and use the present generating stations as sub-stations and centres for distribution. The Metropolitan Electric Company have already built a large station for this purpose at Willesden.

At Hampstead, single-phase alternating current is in use, and although the alternators and engines are of different patterns and manufacture they run well in parallel. The synchronising is done by spots painted on the poles, which, when lighted by alternating arcs, indicate to the engine driver whether the incoming set is running too fast or too slow. This plan works well, but as it often happens that a new set has to be run up during daylight, the spots cannot be seen very clearly in the conflicting light.

At East Ham the 3-wire, 480-volts lighting system has been adopted, mainly to enable the same generators to be used either for lighting or traction, but not simultaneously, of course. Difficulty is experienced in getting 240-volt lamps of efficient make, and having a fair life.

At Berlin some of the power-stations were equipped with obsolete machinery, but the one that attracted my particular attention was at Moabit. There were three magnificent sets, each consisting of

Sulzer horizontal double tandem triple expansion engines of 4,000 H.P., coupled to gigantic three-phase alternators of 3,000 K.W. 6,800 volts running at 83 revolutions, periodicity 50. After inspecting this station in company with a party, I was privileged to return the following day and examined it with more attention. Three sets were running in parallel on about two-thirds full load, and at my request the engineer in charge was good enough to transfer the load from one to another, synchronise, and in other respects prove how perfectly the plant was under control. The synchronising current was very small, and the sets ran perfectly in parallel notwithstanding their very low speed. This result was largely, if not entirely, due to the system of damping coils inserted in the laminated pole pieces. These consisted of a number of bare copper rods about half-inch in diameter sunk just below the level of the iron of the pole pieces, and these rods were all short-circuited at the ends by a rectangular casting. This casting also acts as a flange to hold the exciting coil in place. Each field pole is removable separately, sideways, so that a burnt coil can be readily replaced. As regards the stationary armature, it was of the utmost simplicity, and practically indestructible. The laminated plates of which it is built up have rectangular slots punched out very close to the periphery (a slot being afterwards cut through), a rectangular tube of micanite about one-eighth inch thick is pushed into the slot, and a copper bar is inserted into the tube. The micanite projects a couple of inches beyond the core to prevent surface leakage, and as there are no convolutions there can be no internal short circuits of coils. The copper bars are coupled at the ends by suitably shaped connectors of copper strip. Being such large machines the solid rods are capable of generating the full pressure of 6,800 volts, and it seems impossible that such a machine could break down electrically.

By the courtesy of the A.E.G. I was enabled to meet Professor Dobrowolsky and to have certain points explained upon which I was not clear. Chiefly among these was the question of damper windings. It seemed to me that if eddy currents were induced in them such currents meant wasted horse-power, and if no currents were there, what was the object of the coils? It was explained to me that if alternators fitted with the damping coils and driven by engines (or turbines) having a uniform torque, were run in parallel, there would be no eddy currents and consequently no waste of power. The coils would simply be idle. But if the prime movers were not of uniform torque, eddy currents would be generated in proportion to the tendency to get out of step, which would hold the machines in phase. The worse the engine the more work there would be thrown on the coils. The coils, therefore, though being located on the electric generator, would really be acting as an additional flywheel to the engine.

A very ingenious boosted rotary was at work in the Moabit Station. Naturally a drawback in using an ordinary rotary is that the ratio of transformation from alternating current to direct is fixed once for all. Therefore, in case of a heavy load coming on the direct side of one rotary, it would be necessary to raise the alternating voltage, which might be inconvenient to other lightly loaded rotaries fed from the same source.

This difficulty appears to be overcome by a method patented by Dobrowolsky, which consists of an ordinary rotary coupled on the same shaft to a booster provided with a shunt-wound field magnet. The polyphase current (in this case six-phase) was fed to six rings, from each ring a certain number of convolutions was taken round the booster armature and then coupled to six points on the armature windings of the rotary proper. The booster windings and pole pieces would be suitable in number to the periodicity employed. Now the action is as follows :—If the field magnets of the booster are not excited, the polyphase- is converted to direct-current in the ordinary manner, and in the ordinary ratio of voltage, but if the field coils are excited in one sense they add volts (due to the booster windings passing them at the proper periodicity), to the incoming alternating current, and if the fields are excited in opposite sense the induced voltage opposes that incoming. By this means a considerable variation—about 15 per cent.—can be obtained on either side of the normal.

A good exhibit of the Nernst Lamp was on view in Berlin. There seems to be a difference of opinion about the peculiarities of this lamp. In Berlin I was told it would work on an alternating- or direct-current circuit, and that its life was between 200–300 hours. Efficiency 1·4 to 1·5 watts per candle-power. For the large-sized lamps an iron resistance to steady the current is enclosed in a glass tube to prevent oxidation. For the small sizes a platinum resistance is used. A temperature of about 600 degrees F. is required before the filament becomes a conductor, and this is usually attained in from ten to thirty seconds. In London I was told that the life of the lamp was not determined, but that it was about the same as an ordinary incandescent lamp. I was also informed that it would not work on an alternating circuit, and that when used with a direct current its polarity must not be altered once it was started up. Two kinds of lamps are manufactured, one with an automatic heater and the other without. Of course no vacuum is required, and it is very interesting to blow out a lamp. If fitted with self-lighter it restarts in a few seconds, if not it must be relit with a wax match or spirit lamp.

In Berlin and Hanover electric trams are running which take power from an overhead system when outside the town, and from accumulators they carry when within the city limits. The cells are charged from the trolley wire.

In Naples the trolley wire has an insulated strip on its upper surface to obviate the use of guard wires. This strip appeared to be sufficiently flexible to follow the vertical movements of the trolley wire. It seems to be successful, though I hear that in other towns where strips of wood have been tried, the system has been abandoned owing to the difficulty of attachment and to the tendency of the strip to twist round.

The present English practice, as adopted in London, Glasgow, Portsmouth, and other towns, is to have double-deck cars with a pedestal trolley, but with no top roof. In passing under bridges the trolley pole is sometimes horizontal and the live wire within reach. It seems strange that the English conservatism, which prevented the early adoption of the overhead trolley wire, owing to its danger, should

have now gone to the other extreme and sanctioned the universal use of cars with exposed upper seats.

The American cars are practically all single deck, either on 4-wheel trucks or bogies. In New York the original cable conduit has been converted to an electrical system, and there is a splendid service along the principal streets of the city, the cars having but a few yards headway. There are a few accumulator cars in use, and still a few horse cars running in the lower part of the city. There is an excellent run between Buffalo and Niagara—about 30 miles, where long bogie cars are used. Outside the town they run at a very high speed—probably 45 miles an hour in some places.

Several of the existing New York power-stations are located in the city itself, and, owing to lack of water, work non-condensing. The Edison 3-wire 110-volt system is practically universal, and one does not see any 220-volt lamps. The arc lamps in the streets are chiefly of the original Brush or Thomson-Houston pattern, and often on wooden poles, and they do not compare as regards steadiness, brilliancy, or neat appearance with the Brockie-Pell lamp, now almost universal in England. I must here mention, however, that the very worst arc lighting I saw was in the City district of London, where Brush lamps are installed and fitted into lanterns with corrugated glass panes. These corrugations may be of the correct shape to give a theoretically perfect distribution of light, but unfortunately the ribs collect the dust to such an extent that the actual light given off is very poor in quantity and very unsteady.

The new lighting and power stations for New York (to replace those in the centre of the districts) are located on the eastern side of the city and at the water's edge. The first one visited was that of the New York Edison Co., not yet working. This, when complete, will be the largest steam-power station in the world. There will be 56 boilers, Babcock & Wilcox type, in two tiers, capable of working up to about 100,000 H.P. The engines are vertical, 16 in number, 3-cylinder compound, made by the Westinghouse Co., are each of 9,000 maximum horse-power or 5,200 economical horse-power, and arranged to work with superheated steam. The Westinghouse generators, direct-coupled to engines, are 3-phase, 6,600 volts, maximum output 4,500 k.w., speed 75. At present but two sets are being erected, and eight more are being built. The station is provided with four steel smoke-stacks, brick-lined, 17 feet in diameter, and 150 and 200 feet high above grates. The engine-room is necessarily of immense height, and the floor space measures 272 feet by 118 feet, which works out at 0·6 of a square foot per horse-power.

The next station visited was that of the Metropolitan Street Railway Co. Here Babcock & Wilcox boilers to the extent of 21,000 H.P. are installed. Eight Allis vertical cross-compound engines are erected (three more are under order), each of 6,000 maximum H.P. The generators are of General Electric Co. make, 6,600 volts, 3-phase, 3,500 k.w., 75 revolutions, 25 cycles. This plant is running.

From there we went to the Manhattan Street Railway Company's power-house, where provision is made for 32,000 H.P. of B. & W.

boilers, eight compound engines of Allis manufacture, combined vertical and horizontal cylinders each of 12,000 maximum H.P. Each engine will drive a 5,000-k.w. 11,000-volt 3-phase Westinghouse generator. There was only one set being erected at the time of our visit, but we were all more or less staggered at the gigantic size of the generators—the revolving field was 32 feet in diameter and the external diameter of the armature 44 feet.

Two other smaller stations were afterwards inspected. That of the Brooklyn Edison Co. had four 1,000-H.P. engines, each driving a Westinghouse 3-phase alternator of 750 k.w. 6,600 volts, 94 revolutions, 25 cycles; and the Bay Ridge Brooklyn Station had two engines of 6,000 H.P., one of 2,500 H.P., and one of 1,500 H.P., driving generators, two of 2,850 k.w., one of 2,000, and one of 1,000, all 3-phase 6,600 volts, 25 cycles.

It is interesting to note that, whether the power-station is for lighting or power purposes, the generators are of 3-phase; usually 25 cycles and 6,600 volts seems to be a standard both in America and Germany. Probably this pressure is the highest that is produced when using solid copper bars in the armature, and when the generators are of about 3,000 k.w. The largest machine, 5,000 k.w., is for 11,000 volts for probably the same reason.

There is very little difference between the generators built by the Westinghouse, the General Electric, or the German companies. They all have stationary armature with solid copper bar conductors and revolving field magnets. The shapes of the armature slots vary slightly, some being oval and others with parallel sides, in which case the conductor is held in with wooden wedges. The Germans prefer narrow armatures of large diameter, the Americans wider and smaller. The switches for dealing with high-pressure and heavy currents are of the oil-submerged pattern operated either by compressed air or by motors. The motors wind up a spring which is suddenly released, thus causing a very quick break, or rather a series of breaks under oil. Overload circuit-breakers are used, no fuses. Three-core paper-insulated cables are favoured for underground work up to 11,000 volts. It is not unusual to find transformers in use which step down from 11,000 to 350 so as to give 550–600 volts direct current through rotaries for tram service.

After visiting the Crocker Wheeler works at Ampere, and staying a short time at Albany, we reached the works of the G. E. Co. Here we saw all the various kinds of plant in process of manufacture. One novelty noticed was the winding of field magnets with bare copper strip put on edgeways.

A high-speed experimental car driven by 3-phase motors was running on a short experimental track in the works. It was only working at about 500 volts, but the idea was to have 10,000 volt lines, the three wires being one above the other at the side of the track, and to carry transformers on the car. An electric train on the multiple unit system, where the movement of the master controller operated electric switches simultaneously on all the other cars, so that all the motors on the cars were working under the same conditions, was shown in motion.

From Schenectady a special train took us to Buffalo. As this city, including the Pan-American Exposition, obtains its power for all electrical purposes from Niagara Falls, I will describe that station first. At the new Niagara Falls power-house ten 5,000-H.P. 2-phase generators, built by the Westinghouse Co., are installed. These are of quite unusual pattern, having vertical shafts, stationary armatures, and umbrella-shaped revolving field magnets. The turbines that drive these machines are on a level with the river bed, the vertical shafts therefore being about 170 feet long. Each generator runs at 250 revolutions and gives 2-phase currents at 2,200 volts. The general scheme is as follows: For local service, such as lighting and trams, and for manufacturing industries, such as aluminium, calcium carbide, carborundum, lead reduction, and many others, to a total of 17,000 H.P., the 2,200-volt current is supplied direct and transformed to the various kinds of current and pressures as required at the different factories. The transformations are made by static transformers, rotaries, or 2-phase motors driving generators; thus any voltage direct, alternating, and any phase can be delivered. For intermediate-distance transmission the 2,200-volt 2-phase is transformed to 11,000 3-phase and sent direct underground, and finally transformed to 2-phase and down to 2,200 volts as originally delivered. Total, 11,500 H.P. For long-distance transmission, such as to Lockport (28 miles) and Buffalo (26 miles), the 2,200-volt current is transformed to 3-phase 22,000 and run overhead; total H.P., 20,000. The switchboard in the power-station has two sets of bus bars with five machines on each; these bus bars can be paralleled if desired. The switches are pneumatically controlled. The measuring instruments are of a novel pattern, being of a revolving disc type on vertical spindle; the pressure, or current, is marked on the edge of disc and comes into view through a small window on face of the board. A new synchronising device is adopted which consists of a large dial upon the face of which a hand revolves either one way or the other, depending upon whether the incoming machine is going too fast or too slowly. I was not able to ascertain the connections, but it worked very well, as we could see from the way in which a new generator was run up. No written description can give an adequate idea of the immensity of the mechanical, electrical, and hydraulic engineering skill that has been brought to bear upon this unique plant with such satisfactory results. When one descends by a lift to the different galleries, and finally reaches the level just above the turbines and feels the vibration and hears the rushing of thousands of tons of water just beneath one's feet, one recognises the terrific power that is being dealt with. The cables from the bus bars pass underground through a tunnel, where they are suspended on hangers, to the transformer-house, where they are connected to seven step-up transformers, each of 1,875 k.w. capacity. They are about 12 feet high and 8 feet diameter, are oil-insulated, and have a cold-water supply laid on which is allowed to run to waste—there is plenty of it. These transform from 2-phase 2,200 volts to 3-phase 22,000. Before the high-tension current leaves by the overhead lines it passes through various lightning arresters of the Wurtz, disc, and other patterns, and through large

choking coils. I happened to be in the place when the lines were repeatedly struck, but no damage was done, though there was a brilliant display of fireworks and much noise. The extra high-tension switches have breaks of about 5 feet and are coupled together in sets of three.

There are three 3-phase lines to Buffalo, two of copper and one of aluminium. The latter is not so neat as the copper, but I understand that the saving in cost by its use was 12½ per cent. The joints are made mechanically. The lines are run on insulators fixed to wooden poles, and the wires are spiralled. A telephone line is run on the same poles for 26 miles, and speech is quite easy. The loss of potential on the lines at full load is 3 per cent. The line is tapped for a branch to Lockport, where a 1,000 H.P. rotary feeds the trolley lines and a 300 H.P. rotary, a 3-wire 220-volt system for lighting. At Tonawanda some 2,000 H.P. is also tapped from the lines for trams, arcs and glow lamps. The lines continue to Buffalo, where there is a sub-station in which seven 2,250 k.w. transformers, one spare, reduce the 22,000 to 11,000, the 11,000 3-phase is sent by seven underground feeders to various sub-stations in Buffalo. The 22,000 is reduced to 11,000 because the engineers were not sure of the effects that would be produced by having the higher pressure on an underground network. Each cable carries 4,000 H.P., is lead covered, and laid in concrete. One sub-station in Buffalo receives the 11,000 volts, transforms it down to about 310, when rotaries of 750 k.w. each deliver 550 volts for trolley line work. There is no complication: all the transformers are paralleled on both high and low-tension sides, and all rotaries are in parallel on both 3-phase and direct-current sides. The sub-station is remarkably small and compact considering that it deals with some 4,000 H.P.

The Buffalo Co.'s lighting station receives its 11,000-volt current, transforms it down and passes it into some dozens of 3-phase 200 H.P. synchronous motors. Each motor has two 125-light 6,000-volt direct-current Brush arc machines coupled direct to it. These motors are started up (without exciting current) by inserting a choking coil in the main circuit and letting eddy currents be generated in copper rings round the pole pieces. When in step they are suitably excited. These machines make a considerable noise in getting up speed. Some 3,000 arcs are fed by these machines. In the same station is a huge 1,200 H.P. 3-phase motor (the largest yet built) driving a pair of direct-current generators, each giving 2,665 amp. at 150 volts at 375 revolutions. This supplies the low-tension 3-wire system. The same station contains numerous other rotaries, also 3-phase to direct motor generators. The Pan-American Exposition absorbs 5,000 H.P. for lighting purposes and motors. A branch from the 11,000-volt sub-station is run to a bank of nineteen 250-k.w. air-cooled General Electric Transformers which reduce it down to 1,800 volts for distribution about the grounds. It is further reduced or transformed to direct-current as required for various purposes. About 300,000 lamps were installed at the Exhibition, but not all on at once. For the decorative electric illumination of the various buildings 65,000 8 c.p. clear glass lamps are

employed. This is the first time lamps have been run in any number at such a low periodicity as 25 cycles. It is important to note that no flickering was appreciable to the eye.

The decorative lighting was most effective; all the principal buildings, domes, and the great Electric Tower were lighted right round, so that the full effect could be seen from any point of view. The method of lighting was novel and gave a very grand effect. At a certain hour in the evening, most of the outside lamps being out, the whole of the 65,000 lamps over the various buildings came up all together and very slowly, at first dull red, then brighter red, then dull yellow, then bright yellow, and finally up to full power. This was probably the most attractive feature in the whole Exhibition. The electrical arrangement for carrying this out was very simple, it was merely a large water resistance inserted on the 11,000-volt side, suitable plates being gradually lowered into the liquid until finally the resistance was short-circuited. This had the additional advantage of giving the generators and turbines time to get into their stride, as even with a large plant like that at Niagara, the sudden turning on of 65,000 lamps might lead to trouble.

All the large American electrical firms were well represented at the Exhibition, especially the General Electric Co., and the Westinghouse Co. The former exhibited a constant-current transformer, designed to feed a number of alternating enclosed arcs in series. It worked well. A novelty also shown by them was an enclosed arc lamp working direct off a 220-volt circuit. This lamp had an arc about one and a half inches long and took but a small current. It burnt steadily, but with the usual blueish tinge noticeable with other enclosed arcs.

It may be wondered whether the Niagara plant ever fails. I regret to say that it does occasionally. On one evening during my visit, the whole of the Exhibition lights, street lights, and tramcars in Buffalo shut down for about two hours. It did not seem to me to be polite to enquire from the officials what the cause was, as I knew they must be sufficiently worried already. I believe, however, the trouble was due to faults on the overhead line.

Close to the present power-station at the Falls an extension is being laid down for another 50,000 H.P. on the same lines as the present one. The wheel pits, penstocks, etc., are in place, but the whole thing is on such a huge scale that it will probably be years before it can be completed. Meanwhile the present station is fully loaded: even during the daytime nine out of ten sets are running, but it appears some of the load comes off before the lighting starts up. The tail race tunnel is large enough to take the exhaust from the new station as well as the present one. It is worth mentioning that the outflow from the tunnel when compared to the water flowing over the Falls is a negligible quantity.

On the banks of the Niagara River exist a few more comparatively small power-stations in which the generators are of the ordinary kind driven by horizontal turbines—the plant is located near the water level and in one case the current is conveyed up to the bank by aluminium rods fastened to the penstock. The penstock is about six feet in

diameter, and the equivalent electrical energy returns by three rods two inches broad.

I had the novel experience of riding thirty miles on an electric motor car. This car was one of many electrically driven vehicles belonging to a Buffalo Co. It had two 2½ H.P. motors, one geared to each rear driving wheel, so that no differential motion was necessary. The voltage was 88 and the different speeds were easily acquired without inserting any resistance by changing the cells and motors from series to parallel in various combination. The car held four persons, ran at a maximum speed of twenty miles an hour, and was said to be good for seventy miles on a fair road with one charge. I was rather sceptical on this point, and as my host admitted a previous run of thirty miles, I persuaded him to keep to the tram route on the return journey, but my suspicions proved to be groundless. Pneumatic tyres are used in winter and solids in summer, as it is found the former are liable to burst with the heat. Many electrically driven hansom cabs ply for hire in Buffalo. They appear to be popular and work well, but they are extremely ugly in design.

I was struck with the small number of men who are employed in running of large stations in America, and also at the youth of the engineers in charge. The gentleman in charge of the great Niagara power-station, the overhead lines, and the various sub-stations, is certainly under forty years of age.

GLASGOW LOCAL SECTION.

PRACTICAL NOTES ON CONTINUOUS-CURRENT DISTRIBUTING MAINS.

By JOHN C. A. WARD, Associate.

Paper read at Meeting of Section, January 14, 1902.

In dealing with the subject of continuous-current electricity supply one of the many difficult problems which an electrical engineer has to face is the preparation of a scheme for the laying out of a suitable system of distributing mains. And, naturally, the first question which arises in his mind is, which is the system most suited to meet the requirements of the scheme under consideration?

The most prominent of the several systems of underground mains at present in use are as follows:—

1. Vulcanised rubber or bitumen-insulated cables drawn into iron or earthenware ducts.
2. Lead-covered, rubber-, jute-, or paper-insulated cables, drawn into iron or earthenware ducts.
3. The above-mentioned covered with a steel armouring and laid direct in the ground.

The above-mentioned laid in iron, earthenware, or wooden troughing on what is called the "solid system," that is to say, the troughs are filled with bitumen or pitch-compound with a view to affording a non-hygroscopic protection to the cables.

4. Bare copper conductors, supported on porcelain insulators in brick, iron, or earthenware culverts.

There is at present a great diversity of opinion among engineers as to the respective merits of these systems, some being condemned from one quarter and recommended from another. A reason for this may perhaps be found in the fact that systems of distribution, until very recently, have not received that study which so important a branch of an electrical undertaking entitles them to.

In the first place certain localities and conditions which may permit of one system being adopted with success are not suitable to the requirements of another, and consequently a certain system, if put down in a town where the local conditions are unsuitable, becomes condemned unnecessarily. For example, one of the simplest and cheapest of systems of distributing mains is that in which bare copper strips are mounted on insulators and laid in ducts under the footways of the public thoroughfares. To ensure the proper working of such a system levels must be carefully studied, with a view to both the draining of accumulations of water, and the conveying of explosive gas to points from which it may be removed by ventilation.

In a small town in which there is ample room under the footways for the laying of mains, and where straight runs and required gradients may be easily obtained, a copper-strip system could with advantage be adopted. But in introducing a system of copper-strip mains into a large town or city, circumstances of an entirely different nature arise. Draw-in and inspection boxes cannot be put down at the right places, large gas and water mains, &c., block the way, and, more often than not, the route of the mains, owing to cellars under the footways, has to be diverted into the roadway. It may be assumed that the remarks on bare-copper systems apply equally well to many of the other systems mentioned, bare copper having been taken as an example to illustrate the importance for taking everything into consideration before forming an opinion detrimental to any particular system. Unless the system can be put down in its entirety, that is to say, with due attention and care given to all the little accessory points which go to make it a good system, it is needless to point out that troubles arise which soon give it a bad name.

Before proceeding to the comparison of different systems, it might be well to mention a few facts on some very important points that effect the efficiency of continuous-current distribution. Mains break down owing to faults in manufacture, and to mechanical injury received when under the streets or in the process of laying; but there is no form of destruction so difficult to contend with as the action of electrolysis, which commences where insufficiently guarded against at the moment that the mains are made alive.

The phenomenon known as electric osmosis, whereby moisture tends to accumulate at the negative conductor, and is directed away from the positive, can be readily observed in carrying out a simple experiment with an E.M.F. of a few volts, and it can be well understood to be a matter of great importance when it is known that it commences to take place directly a continuous current is supplied to conductors, and that it varies in intensity according to the E.M.F. at which the conductors are arranged to work. The continual heaping up of moisture at the negative conductor, where exposed, tends to lower the insulation resistance between that conductor and earth; and especially in cases where the middle or neutral conductor on a three-wire system is deliberately earthed, minute currents tend to pass from the neutral conductor through the earth and on to the negative conductor, resulting in electrolysis.

Where metallic sheathings of underground cables have deteriorated and no mechanical injury is found to account for it, it is not only necessary to examine the soil or ducts enclosing the cable, as the joints in the neighbourhood may very often be the cause. Ends of cables brought into manholes where the conductors terminate in thimbles or sockets are very often sealed by means of lappings of so-called insulating tapes, over the socket and back on to the lead covering of the cable. Great care may be taken to try to hermetically seal the ends of the dialectrics at these points, but a feature nearly, if not quite, as important is very often overlooked, and that is the creeping electrolysis which will set up across the tape between the bare socket at the end of

the conductor and the metal sheathing of the cable. It is usually the rule to coat the tape lapping with an enamel paint, but this is not a safe expedient, as more often than not salts, due to electrolysis, are noticeable deposited on the tape, and will be found to have even worked through under the layers of the tape between the socket and the metal sheathing. Fresh coats of paint are of course of no use under these circumstances, as they only hide the trouble which, when once started, continues to increase, the result being the deterioration of the sheathing, especially at points where the sheathing *may be lying in moisture*, perhaps hundreds of yards away.

One of the ways in which to circumvent this trouble, and yet continue the use of bare ends in manholes, is to do away with tapes of all descriptions, and to seal the cable ends in an end-connection box filled with compound, bringing the bare socket through a gland of insulating material such as ebonite or porcelain, the gland containing several deep corrugations, or a very long surface, so as to present as far possible a

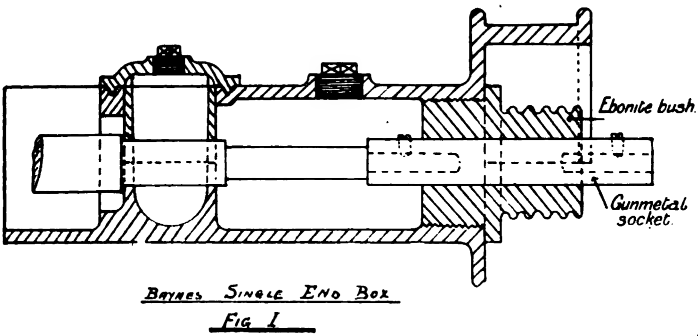


FIG. 1.

high resistance to the creeping effect. These surfaces are easily kept clean from time to time by wiping them with paraffin ; but experience has shown that even with these contrivances the action still goes on, although reduced to a minimum. Figure 1 represents an end box as described above. This box was designed by Mr. Sydney Baynes while officiating as Chief Engineer to the Bradford Corporation, and Mr. Baynes appears to have been one of the first electrical engineers to recognise the importance of protecting ends of cables in this manner. A box of this description has the twofold advantage that it not only provides a seal of compound for preserving the insulation at the cable end, but owing to the corrugated insulating bush surrounding the conductor, surface leakage or creeping is reduced to a minimum.

The above remarks on the question of electrolysis of metal sheathing lead up to another point of serious consideration, and that is, the protection of sheathings from the effects of stray currents, and heavy rushes of current, when, due to a breakdown of the insulation, metallic contact is made between the conductor and the metal sheathing. Every precaution should undoubtedly be taken to make a

thoroughly good metallic connection between all metal sheathings of cables, through the joint-boxes, manholes, and ends terminating at the generating station.

Faults are very often discovered at metal joint-boxes due to the want of efficient bonding between the sheathings of the cables terminating at either side of the box. Strips of lead of small section, if used for bonding purposes, or a single strand of say No. 16 gauge copper wire, although being sufficient to guard against the effect of electrolysis at points where the lead sheathings of cables terminate at the glands of the joint-boxes, have been found in many cases to have been fused away, when, through defects in insulation, heavy currents have passed along the lead sheathing and through such bonds. The disconnection between sections of lead sheathings having remained undiscovered, has resulted in faults at the glands of the joint-boxes owing to the lead having arced on to the box at the point of contact, when the occurrence of other faults has caused currents to flow in the same direction. In many instances attempts have been

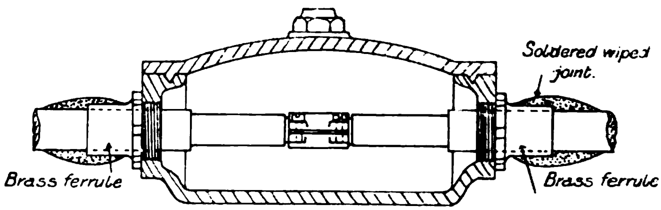


FIG. 2.

made to guard against this by enclosing the lead sheathing in a wooden bush at the point of entry to the box. Wooden bushes buried in the ground, however, in time absorb moisture, and their insulating properties are then destroyed. The best method to insure continuity of metallic circuit throughout the system is to securely bond the lead sheathing of the cable on to the box itself. One of the most suitable designs of joint-boxes to meet this requirement is a box with brass ferrules screwed to the cast-iron sides (Fig. 2), the cables passing through the ferrules, and a wiped joint between the ferrule and the lead sheathing making not only an excellent bond, but also a water-tight joint if wiped properly. Unfortunately it is not possible in all parts of the country to obtain plumber-jointers, and if a plumber and a jointer have to be employed the expense is a consideration.

A form of bond lately introduced will be seen in Fig. 3. This does away with the necessity for plumbing, and secures excellent metallic contact between the box and the cable sheathing. Efficient bonding should be carried out irrespective of the intentional earthing of any of the poles of the system, as, although this may be done, it will still be found that, owing to a complication of faults, heavy currents may be travelling on the leads between points considerably distant apart.

On a three-wire system earthing the neutral conductor certainly

would tend to reduce this trouble to a minimum if the neutral could be efficiently earthed at all points of the system. There is objection to this, however, from another point of view, the engineer preferring to have his neutral earthing devices under control at the generating station, in connection with earth-testing instruments, by means of which a defective outer may very often be traced before it has had time to break down.

Besides, although endeavours may be made to earth one pole of the system at all points, the difficulty is to do it efficiently. Earth-plates

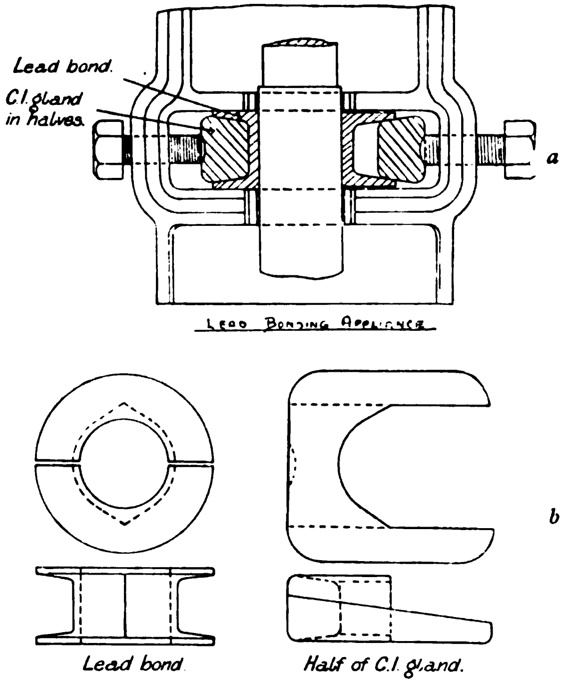


FIG. 3.

forming good conductors may be put into the earth, but as the substance constituting the subsoil or "earth" may in some places be comparatively dry, and in others very wet, and may consist of different classes of soil, the differences of electrical resistance of these various substances means differences of potential at points in the earth between which a large current may have to flow in travelling from one earth-plate to another. One form of earth-plate used in Glasgow is a six-feet length of unpainted cast iron four-inch pipe driven vertically into the earth and connected by means of a special bond to an "earthing" copper conductor in the section-boxes. This has, in many cases, been found to be very effective, because it not only presents a large surface inside and out to the earth, but acting as a drain fills with water and in a measure keeps

the surrounding earth moist. Cases have been known in which a current has flowed along the metal sheathing of a cable and, instead of going to earth through the earth-plate put in for the purpose, the bulk of it has travelled along the sheathing of the cable to a cast-iron joint-box, whence it arced from the bottom of the box through a layer of mud on to a water main. This was found to be owing to the fact that the earth-plate, which was of cast iron, was buried in the footway in a comparatively dry bed of sandy soil, and therefore was not making nearly such a good earth as the joint-box in close proximity to the water main. In mentioning cast iron as having been used for earth-plates, it is by no means intended to infer that it is the best material to use, as in time a

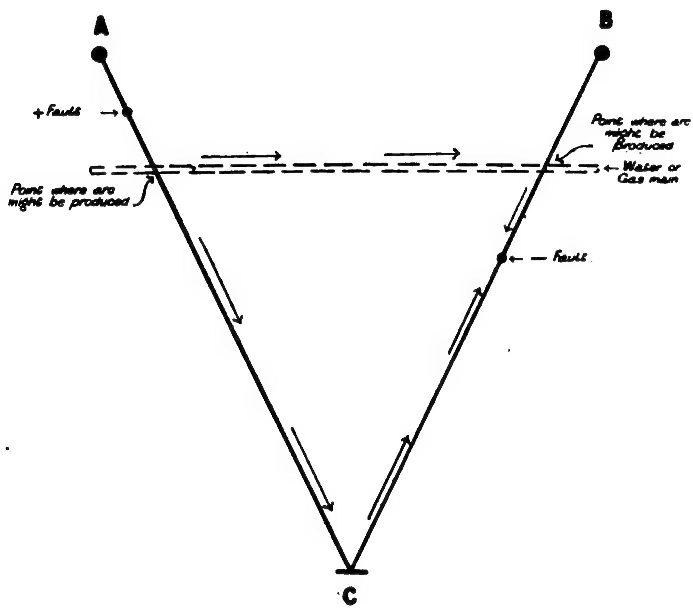


FIG. 4.

skin of oxide of iron forming on the metal tends in a measure to insulate it. Considering, however, that copper earth-plates, if put in in large quantities, might become very expensive, and that some of the plates when put in might be of no value (owing to the low electrical conductivity of the surrounding earth), cast iron appears to be quite as satisfactory as required for the purpose.

The necessity for earth-plates on metal sheathed-cables may be seen from the accompanying diagram, Fig. 4. "A" and "B" are the ends of two feeders on a system of underground mains, "A" being a positive conductor of "A" feeder, and "B" the negative conductor of "B" feeder. Assume that the insulation of both conductors is gradually breaking down. Suppose the sheathings are not intentionally earthed at any spot, and the insulation of both "A" and "B" breaks down practically

at the same time. There will naturally be a tendency for a circuit through the earth between the faults by the path offering the least resistance. If the lead sheathings of the cables are thoroughly bonded across the joint-boxes and also connected to one another through the central station, there will be a metallic circuit of lead between "A" and "B" through "C." The resistance of this circuit will vary with its length, which, as will be seen from the diagram, is greater than the distance between the faults, and a lower resistance may be obtained along the lines at a certain point or points where the lead sheathing may be in near proximity to a gas or water main laid in a direction which crosses the two mains "A" and "B." There will be at these points a tendency for a current to pass between the lead sheathing and the water or gas main, and an arc, destructive to the lead sheathing, may be produced. Suppose the leads are not bonded together across the joint-boxes, there may be an arc formed between the lead sheathing and the box owing to the box making a better earth. In fact there are so many possibilities to be derived from a study of the diagram, that the conclusion seems to be that earthing of the sheathing at as many points as possible, combined with the thorough metallic bonding of all points where the sheathing is broken at joints, is most desirable. The above example is also applicable to the points raised on the subject of electrolysis due either to bad joints or leaky ends on the distributing system, or to stray currents from the rails of an electric tramway system, and also to systems in which, owing to the requirements of the Board of Trade, the neutral wire of a three-wire system is to be earthed at the generating station, or even at as many points as possible throughout the system of network.

The question of fusing feeders and networks so that faulty circuits will be automatically isolated and thrown dead with a view to damaging the cable as little as possible, is a subject of great importance, upon which there has been very little public discussion. It appears, however, that electrical engineers are gradually coming to the conclusion that fusing is a necessity, or rather a necessary evil. This subject has been more forced upon us of recent years by the introduction of higher voltages than were used a few years ago, and also owing to the growing popularity of concentric systems of mains. In the days of 100- and 200-volt systems with single conductors laid an inch or so apart from one another, a fault developing into a heavy leak or a "short," was not such a serious matter as it is now on systems where from 400 to 500 volts is the pressure between the conductors, the additional pressure causing far more destruction to the cables if faults occur. With concentric systems it is an absolute necessity to use some means for automatically isolating and throwing dead the faulty sections, otherwise the destruction of the cable proceeds very rapidly, and probably before the faulty section is discovered 100 yards or more of main may be completely destroyed. The problem of satisfactory fusing, however, is a very difficult one to solve. There is no doubt but that for distribution purposes, that is to say, the balancing of a three-wire system and uniformity of pressure, a system in which the network is connected up throughout and not divided into sections, is the most suitable. If, however, such a system is to be fused,

it will be seen that in the event of a fault occurring in a certain locality, current flows to this fault from the several feeding-points through several fuses in series, with the result that, very often, instead of fuses blowing in the neighbourhood of the fault, they may be blown at a considerable distance away, thus throwing dead large sections of distributors, the supply to which should not have been interrupted. It may be of interest to show what has been done in Glasgow in this respect, as, in this system, endeavours have been made not only to keep the distributing system joined up throughout, but also to fuse as effectively as possible. The diagram, Fig. 5, shows a portion of the Glasgow system of feeders as they are actually laid for feeding into the network, which is also fused, or arranged for fusing, at points indicated on the diagram.

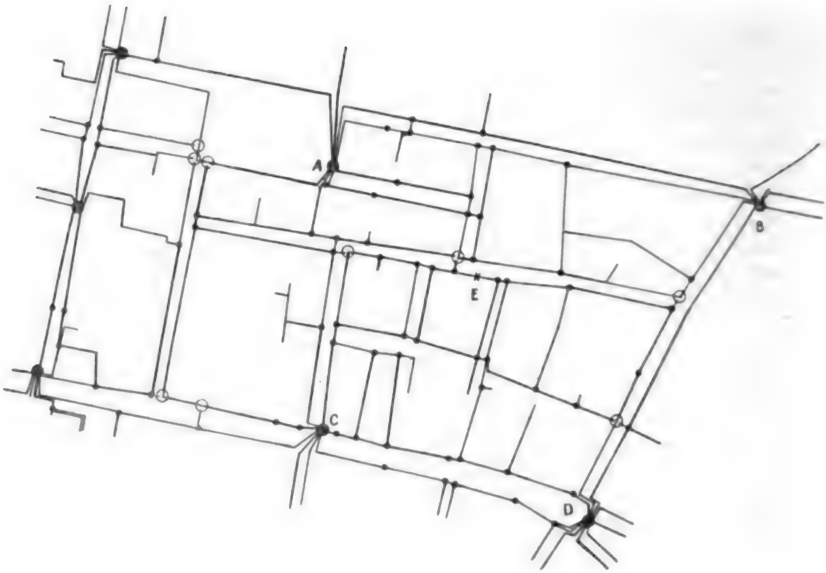


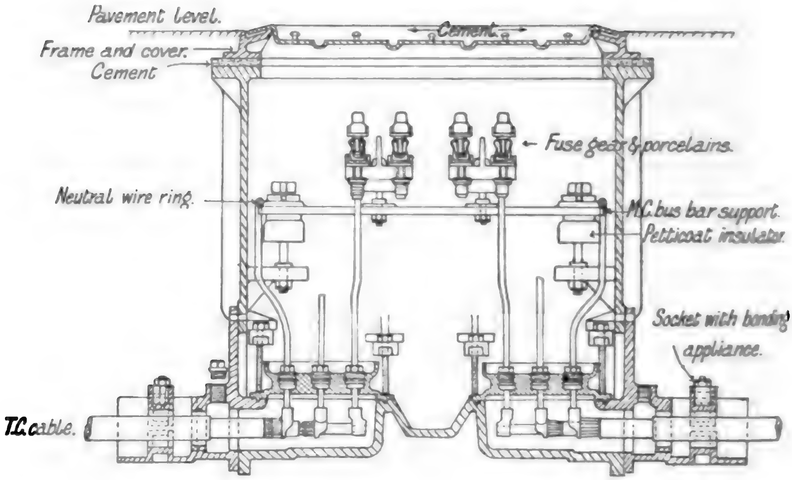
FIG. 5.

It will be seen that at all points where distributors intersect at street corners, disconnecting-boxes are inserted. In these boxes fittings are so arranged that fuses for interconnection may be inserted between any of the distributors. The disconnecting-boxes are shown on the diagram very large with a view to illustrating clearly the points at which links or fuses have been left out. If all distributors are joined together the four feeders will all be feeding directly any section of network independently of one another. For example, in the event of a fault occurring at say a point marked "E," the result will be that fuses will blow between the fault and each feeder, resulting in, perhaps, the cutting out of the whole of the network. Now suppose connecting links or fuses are left out at the points indicated on the diagram by circles. The feeders C and D will supply current directly to the fault through distributors between

them; feeders A and B, being practically unaffected, owing to the disconnecting points preventing them from supplying current into the fault except through distributors joined to the 'bus-bars of the feeding-points C and D, at which points, however, feeders C and D are supplying the fault direct. The rule to be observed is that not more than two feeders shall be connected directly with the distributors laid between them, the connection between these feeders and any others only being made through their respective feeding-points and not by means of distributors joined at points of intersection of the network between feeding-points. This arrangement, although at first appearing a little complicated, is easily accomplished, and, in fact, has in many cases in Glasgow saved the interruption of the supply to many important points of distribution on the occurrence of a fault. It has also the desired effect of reducing interruptions in the event of a short circuit on a feeder. Owing to the difficulty experienced in gauging the fuses to suit continually varying conditions of load and distribution, if a short circuit occurs on a feeder, fuses in the network between that feeder and the adjacent feeders may blow instead of the feeder's own fuse. It will be seen from the diagram that with the disconnections properly arranged the number of fuses thus brought into action is considerably less than would be the case if the disconnections shown were not made.

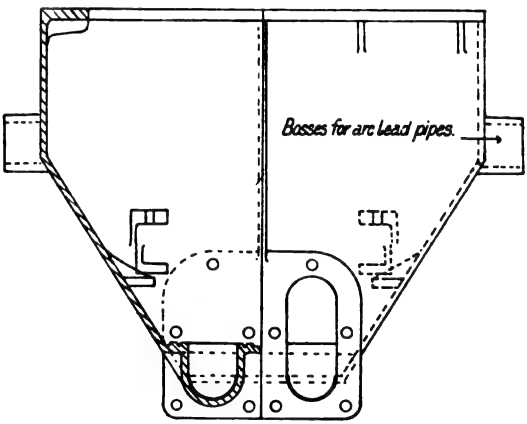
The arrangement described above saves the inconvenience of dividing the network into isolated sections, and this allows of any out-of-balance currents or irregularities of pressure being rectified throughout the general system of network, thereby reducing the necessity for the use of special rectifying arrangements either at the generating stations, or at sub-stations situated at different points in the area of supply. This is of obvious importance in systems in which the balance is not what it should be. It has been mentioned before that at all points of intersection of the network, disconnecting or fusing-boxes have been inserted, and it may be of interest here to give more particulars of the special type of apparatus used in Glasgow for this purpose. In the first place, apart from the question of fusing, there is no doubt but that in a large system of distribution for lighting and motive power, every attention should be given to the question of having the distributors under easy control in small sections, so that in the event of a fault occurring, or a section of main being thrown dead for other reasons, the supply will not be interrupted to a large number of consumers. This is of special importance in Glasgow, where, owing to the varied uses to which electricity is applied, it is even impossible, except by special arrangements, to throw certain sections of the mains dead during the night or on Sundays. The use of disconnecting-boxes at short intervals, and at all points of intersection, is a matter of considerable convenience, and in fact becomes an absolute necessity in the distributing systems of an important area of supply. Secondly, the use of numbers of disconnecting-boxes allows of the distributors being manipulated from time to time, to meet the difficulties arising in endeavouring to fuse the system efficiently, under the condition of the continually changing distribution of the load on the mains. Fig. 6 shows a section of a four-way cast-iron disconnecting manhole. There are many advantages in adopting cast iron instead of

brick or concrete for the construction of manholes. In the first place, if a system of mains is in use which requires earth-plates, and the sheathings of the cables connected together, the cast-iron manhole



Longitudinal Section of Manhole thro' Pockets.

a

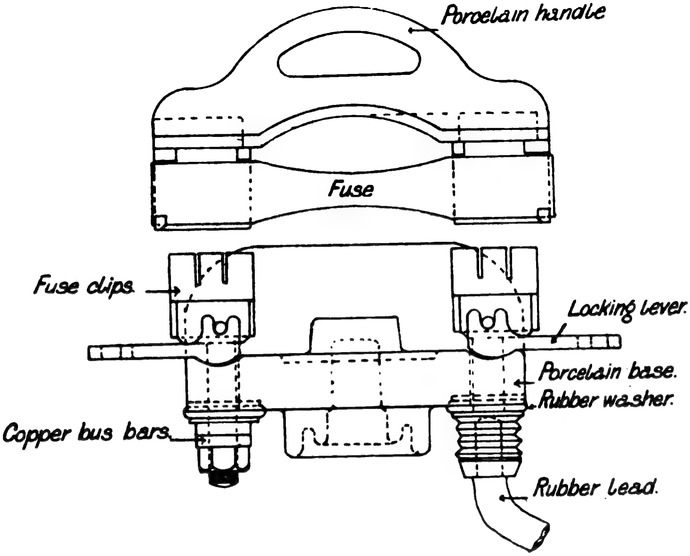


4 Way C.I. Manhole.

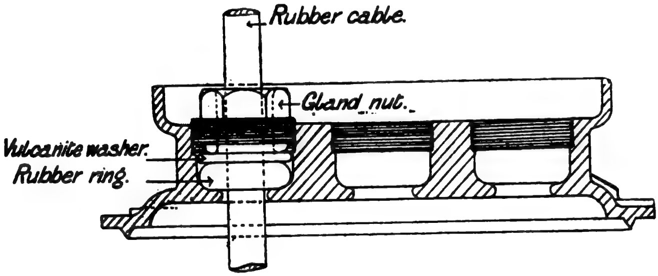
b

Fig. 6.

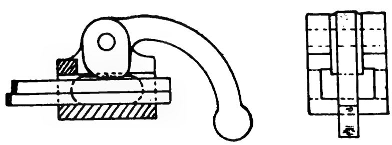
serves the purpose, the cable metal sheathings being securely bonded to it. Secondly, this class of manhole is both gas- and water-proof. Thirdly, the space afforded by using cast iron instead of brick or concrete, can be utilised in providing more room for the fittings inside the box, and this is a matter of vital importance. On entering an up-



Fuse porcelain and gunmetal fittings.



Lid for manhole pockets shewing stuffing boxes.



Neutral wire clamp.

DETAILS OF FIG. 6.

to-date central station one notices the many elaborate and ingenious designs of switchboards in use, many of which, with a view to safety, have separate panels for conductors of opposite polarity, sometimes yards apart; also the best of insulating devices to protect bare conductors from earth; and these switchboards are invariably in a dry atmosphere, and protected from moisture in every way. There is also the best of attention given to steam-pipe arrangements and valves, valves being inserted at different points for giving as many facilities as possible in making the best use of the pipes, and providing for emergencies. If one then has a look into the mains arrangements, one often finds a very different state of affairs. Very few valves or points of control are arranged for, and when there are such, it is seldom found that these are arranged to anything like the best of advantage. Suppose the system be one in which armoured cables or cables laid on the solid system are used, it is the usual practice to bring the ends into a small cast-iron box, and on to connectors arranged so that there is not much more than ½in. to 1in. clearance between any of the connectors of opposite polarity, sometimes much less. All these connectors are built up from a base of wood, probably teak. The box is filled to a certain level with an insulating compound, the terminals for fuses or connecting links protruding through the compound. The box is generally covered with a lid secured in position by bolts and nuts. The box is then surrounded by an outer box of brick used for the purpose of supporting the outer manhole cover on a level with the footway. There are very many points which could be improved upon in such a design. In the first place the clearance between all the conductors of opposite polarity is so small that if once an arc is started between any of the connectors, more often than not the connectors, for at least one or more, sometimes the whole, of the other cables, become short-circuited. If the cable connections in the box are fused, the use of set screws or nuts and studs for securing the ends of the fuses is objectionable on the score that in time the fuses become slack. Vibration due to the street traffic may cause this, but even if it is guarded against by the use of lock nuts, the different expanding properties of the fuse and the conductor owing to the fuse assuming a higher temperature while loaded, cause slackness when the load is off, and the fuse has cooled down. The use of wood of any description is objectionable, because, however well prepared, it may be in a damp store for months before the box is put into use. The fact that the fuse is in close proximity to the compound is inviting a manhole explosion if the fuse blows, for the reason that the gas given off by the burning compound forms an explosive when mixed with air. If the lid is secured by bolts and nuts, valuable time will be expended in endeavouring to get it off, especially if rust has set in. In describing the above, it is not intended to convey that there is nothing more suitable at present in use. The remarks apply to apparatus at present being supplied by manufacturers as a proper standard for distribution purposes. There are no doubt some devices in use that have not all the evils mentioned above, but if so it will be found that they are mostly due to the efforts of central-station engineers, who, finding the manufacturers cannot supply what is required, have been forced into taking the matter up themselves.

In Glasgow the conditions for disconnecting-boxes are rather exceptional owing to the fact that there are several different systems of mains in use, which are as follows :—

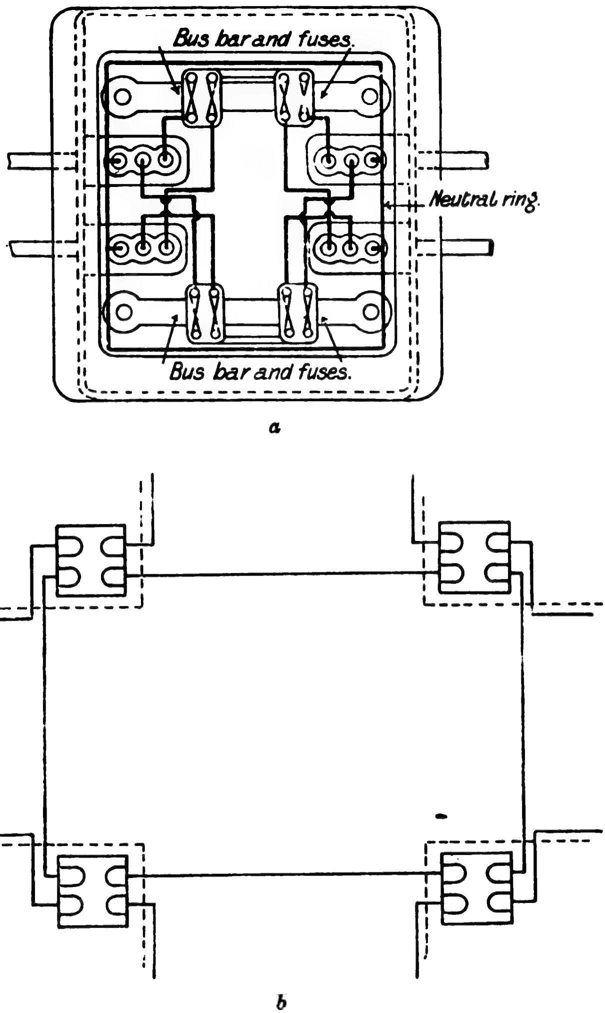


FIG. 7.

Bare copper supported on glazed earthenware insulators and drawn into cast-iron ducts.

Single, steel tape-armoured cables laid direct in the ground.

Vulcanised rubber mains drawn into cast-iron pipes.

Three single conductors laid on the solid system.

Triple concentric armoured cables laid direct in the ground.
Ditto cables laid on the solid system.
Single vulcanised bitumen, lead sheathed, and rubber cables drawn into cast-iron pipes for arc lighting from the network.

The conversion of such a complication of different systems into a three-wire distribution scheme at 250 and 500 volts has been no light undertaking, and has necessitated much attention being given to jointing and disconnecting appliances, with the result that the type of box shown in Fig. 6 is at present in use.

The box, as shown, is for a four-way disconnecting point, but if the sides instead of sloping to the centre at the base are brought straight down it will be suitable for a six-way point. The reason for sloping the sides in the box shown is, in the first place, to save metal; secondly, to save space where not required, thus giving this class of box a distinct advantage over a brick one, which could not be tapered to such an extent. The third reason is that for network distribution purposes in Glasgow it has been thought desirable to use one box at each corner where streets intersect, and not one eight-way on one side of the road with cables crossing from one corner to their several destinations. Diagram 7 shows the general arrangements of distributors and boxes under such conditions. Commencing at the top of the box it will be seen that it contains a flange on the inside suitable for taking a 24-inch manhole frame and cover. On the sides are cast four snugs for securing the petticoat insulators used in supporting the fuse or connecting gear. At the bottom are the inlets for four cable ends. The bottom of the box consists of four pockets, one for each cable, the lids on the pockets being constructed each with three stuffing-boxes, through which single rubber cables make the connection between the cables and the fuse gear. The packing of each stuffing-box consists of a rubber ring and a vulcanite washer, both of which come under compression when the gland nut is screwed into position. A dish is cast round the cover so that when the gland nuts are screwed down, insulating compound is poured into the dish and not only makes the joint doubly secure from moisture, but presents a large insulating surface, with a view to keeping down the tendency for any creeping effect which might take place from the bare fuse connector on to and along the rubber surface of the cable, and down to earth through the box lid. A section of the connections in the interior of the pockets is also shown, the cable in this case being a triple concentric one. A special form of socket is screwed on to the outside of the pocket, and contains the lead-bonding appliances, besides acting as a support to the end of the trough if the cable is laid on the solid system. It might here be mentioned that providing sockets on the outside of joint-boxes for this purpose is very desirable, as it prevents the cable from being injured in cases where the soil subsides and there is a tendency for either the box or the trough to drop from its normal position. Although the box shown contains a triple concentric main, by slight alteration at the glands and bonds single conductors can be inserted. The frame and cover are bedded with cement to the flange at the top of the box, and

can be set to suit the slope of the footway. The cover is designed with a view to being waterproof without the necessity for caulking or draining, and, when in position, effectually prevents water from entering the manhole from the surface of the footway. This is accomplished by making the inner rim of the frame higher than the level of the surrounding footway by about $\frac{1}{4}$ in. all round, so that although the water will fill the recess round the frame, there is never sufficient head of water to force a flow over the inner rim. The cover, constructed out of steel plate stamped into shape, is only $\frac{1}{4}$ in. thick, and this thickness, added to the $\frac{1}{4}$ in. extra height of the inner lip, raises the surface of the cover $\frac{1}{2}$ in. above the level of the surrounding footway. As, however, there is a gradual slope towards the centre of $2\frac{1}{2}$ inches all round the cover the extra height is practically unnoticeable, and, in fact, is no more than found in many other designs of footway manhole covers.

To be able to obtain a frame and cover in which there is no caulking required to keep the water out is of great importance, as it allows of the cover being easily lifted, and at the same time saves the expense of caulking, which amounts to a considerable annual item on a large undertaking. No attempt has been made to ventilate this type of cover, for the reason that, in the first place, the cast-iron manhole is gas-proof, and therefore there is nothing to be feared from gas leaking in from outside. Secondly, it is found in practice that quite 50 per cent. of the explosions which take place in boxes are due to a fault on the cable, or in the end box, burning the jointing compound or insulation of the cable, both of which form an explosive gas which will accumulate in the chamber almost instantly, and cause an explosion. It is obvious that, under such circumstances, any attempt at the ventilating of the cover would not be successful in clearing the manhole, and it is therefore best to cause the explosion to be as light as possible. A loose cover under such circumstances is of considerable advantage, as it acts as a safety valve at the time of explosion, and instead of rising many feet in the air, which it would do if caulked down, very often is known to rise sufficiently to allow of the pent-up vapour escaping and to settle down on the frame again. The cover might be hinged on one side to ensure that if it opened it could not be displaced.

Inside the manhole will be seen the disconnecting or fuse gear. First there are two pairs of petticoat porcelain insulators, each pair supporting a malleable cast-iron bar. To these bars are fixed other insulators, two on each bar, each insulator being capable of supporting two cable conductors so that there are four insulating supports for cable conductors, on each of the cast-iron bars, four for conductors from the positive ends of the cables, and four for the negative ends; the middle or neutral wire cable conductors being brought up to a ring main of rubber forming a square round the manhole, and supported on the cast-iron bar. The neutral wire main, being at earth potential, does not require such careful insulating from earth as the positive or negative conductors; still it is insulated, as the cast-iron bar upon which it rests is supported on porcelain insulators. It will also be noticed that the socket ends of the positive and negative conductors are doubly protected in this way, as they have two insulators in series between them and earth,

and it is interesting to find that since this method of insulating has been introduced there has never been any sign of the creeping which used to be plainly apparent when only one insulator was used.

Turning now to the terminals of the conductors, they are cast in the form of a shank with a socket at one end and a clip at the other. The socket is bored to take the end of the rubber conductor, and each clip engages the link or fuse connection when inserted. On the outside of the clip are pinions which engage an eccentric locking lever. On the stem or shank of the casting is a metal washer, and between the washer and the socket is inserted a rubber ring. The porcelain to which these clips are secured is made to take four clips in the design illustrated, but, where more convenient, smaller porcelains to hold only two clips each may be provided. The porcelain base is slotted at the ends to allow of the shank of the clip being inserted. When the shank is in position the eccentric locking lever attached to the pivots at the side of the clip is pressed from a vertical to a horizontal position, in which position it becomes locked owing to the tension of the rubber washer and the eccentric action of the lever. The cable end is then quite secure, no amount of vibration or shaking being able to detach it unless the lever is raised to the vertical position again. At the end of each lever is a small hole for the purpose of allowing the insertion of short pieces of cable for flashing purposes, or for bridging over the fuse while a new one is being inserted. One clip of each pair is connected to a copper 'bus-bar fixed below the porcelain base, and the other to either the positive or negative rubber leads from one of the four distributors. A porcelain handle is provided with each box, and is designed so that it can engage any particular link or tin strip when there is occasion to remove it from, or replace it in, the clips. This form of handle being removable, is not left in position over the fuse or link when inserted, but is removed and left in the box. Thus it does not become damaged by heat in the event of a fuse blowing. A special form of gun-metal block which fits into the fuse handle is used for holding the strip or fuse in position while it is being inserted in, or removed from, the clips, as shown on the diagram, the strip being U-shaped. The fuse being practically in two strips provides ample cooling surface, and, moreover, the space between the strips allows air-space between the two arcs which form when the fuse blows. This tends considerably to reduce the violence of the arc. The contacts on to the clips are also rubbing contacts and always under tension, no vibration or ordinary variation in temperature between the metal parts causing slackness at the fuse contacts. It is obvious that such an arrangement is infinitely superior to the usual method by which the fuse-metal is never in actual contact with the collecting clips, but is secured to metal blocks by set screws, the blocks engaging the clips and the set screws or studs, while adding to the cost of manufacture, being the very things to avoid, as it is only a matter of time before the fuses will become slack at these points. This, of course, is a very serious matter on a large system of distribution in which many fuses or links are used. In the porcelain bases supporting the fuse clips there are recesses to allow of the names of streets supplied by their respective cables being

inserted under strips of mica, which, while acting as a protection to the name, if a fuse blows, also permits of the name being distinctly visible.

The clamps securing the neutrals of the cables to the neutral ring are, as may be seen from the diagram, of such a design that no tools are required to manipulate them, and vibration tends to tighten rather than to slacken the grip. In this design of disconnecting-box, any one working on a system of mains with which he may not be well acquainted, can with ease manipulate or test any cable practically at a moment's notice, and any disconnection or connection may be made without the necessity for a single tool, or even a pair of rubber gloves.

The preceding remarks, while dealing with certain points on distribution, do not draw much comparison between the many different systems in use at the present day. Some important subjects, however, have been touched upon, these being electrolysis, earth currents, bonding, fusing, and disconnecting points. The discussion of these subjects, however, is of considerable value relatively to the comparison between the different systems.

The question as to whether cables should be laid on the solid system or drawn into ducts is influenced greatly by the experience found with electrolysis, earth currents, and bonding. Cables which rely upon a lead sheathing to keep the moisture out naturally will suffer most from the above troubles, especially in a draw-in system where moisture has accumulated in the ducts. Therefore the remedy would appear to be, in the first place, to lay such cables on a solid system. The lead will then be protected as much as it is possible to protect it from currents creeping on to or off it, at points where the soil may be moist. Even if laid solid, however carefully, bonding of the metal sheathing is found to be necessary, and as a crack in the pitch or bitumen compound surrounding the cable, or air-holes in the compound, may permit of the lead at that point being attacked, the laying of earth-plates at intervals in connection with the lead would appear advisable. If, however, an insulating waterproof covering is used in the place of lead, all the above troubles are avoided; but is there such a covering in existence? Faults sometimes arise on vulcanised rubber and bitumen cables under such conditions that the only conclusion to be formed is that moisture has reached the conductors through defects in the insulating covering, and unfortunately the usual tests carried out at the manufacturers' works before the cable has been certified as satisfactory very often fail to detect these defects. The knowledge that defects in lead sheathings are similarly undetected, and that, however carefully a cable may be lead-sheathed, there is always the possibility for what are called "pin-holes" to be formed in the process, seems to put the balance in favour of cables with a sheathing of insulating material, taking also into consideration the fact that the absence of bonding and earth-plates reduces the cost of the system of distribution to an important degree.

In using rubber or bitumen sheathed cables it should not be desirable to the same extent to lay them on a solid system, but undoubtedly a pitch or bitumen composition surrounding the cable is an extra safeguard against moisture, besides forming in a measure a mechanical protection. A draw-in system, however, has its objections, inasmuch

as, if the ducts consist of metal pipes, a fault occurring on the cable very often burns a hole in the pipe besides fusing the conductor solidly on to the pipe at the point of the fault. It then ceases to be either a draw-in or a draw-out system. Even if the cable is withdrawn the duct will be rough at the point where the conductor has arced on to the metal, and this may seriously injure the cable drawn in to replace the faulty one. A draw-in system also ceases to be of much value for distributors, owing to the number of branch mains which become connected with it as successive installations are connected with the supply. There are also water troubles to be contended with, and gas not only collected from the subsoil, but also generated by the heating of the insulation at the point of a fault.

Of all draw-in systems in use, that in which bare copper strip is drawn into cast-iron ducts and supported on porcelain insulators certainly recommends itself in many ways. Certain sections of distributing mains constructed on this principle are in use in Glasgow on the three-wire system, with 500 volts pressure between the outers, and have up to the present given no trouble. The troubles which have been experienced with bare copper strip in earthenware and brick conduits, caused by the formation of salts on the negative insulators, do not appear where cast iron is used, but the use of cast iron is more apt to cause shorts and earths if the strip is liable to buckle and to touch the cast iron. This may be guarded against by the use of slabs of porcelain laid at short intervals along the bottom of the trough and also, between the strip and the cover. The anchoring of unstrained strip, if carried out at all requires to be very judiciously arranged, as, if careful observations are taken at the manhole, it will be noticed that, owing to the expansion and contraction of the copper effected by varying temperatures and loads, the strip tends to shift considerably in a longitudinal direction. If anchored at certain points this movement is prevented, and the strip commences to buckle. If the strip is laid on edge in the insulators, conductors of opposite polarity may make contact and cause a short circuit. If the strip is laid flat, the buckling will take place towards either the top or bottom of the culvert, but, as before mentioned, this may to a certain extent be guarded against by the use of slabs of porcelain laid at intervals on the top and underneath the strip. Copper-strip systems, in which the copper is strained and secured to specially constructed straining insulators, certainly has the advantage that a tendency to buckling is reduced to a minimum. On a large system of distribution, however, the continual attention and care required might hardly compensate for the advantage to be gained otherwise in the system, and although a distribution system should have quite as much attention as the other necessary points of a supply undertaking, it is certainly desirable so to standardize and design the system, that it may be kept in order with the least amount of skilled supervision that is possible.

The arguments set forth in this paper tend rather to view more favourably a system of conductors covered with an insulating material and laid on the solid system, with a preference for an impervious sheathing of insulating material rather than lead, but there is one

especially important point which has not yet been touched upon. This bears on the relative values of single and concentric conductors. An attempt will be made to enumerate some particular points bearing on each system with a view to forming a comparison between them.

With the use of single conductors, in jointing, each conductor may be individually dealt with while under working pressure without running the risk of short circuits, and only the actual conductors which require tapping need be cut. In the event of a fault occurring on any one conductor it does not necessarily interfere with its neighbour, causing a short circuit, provided a considerable space, say of three inches, is allowed between adjacent conductors. The fault will constitute a leak to earth, and the cable, while faulty, may be still able to carry out its work of distribution without affecting the supply to consumers.

If, however, a neutral wire on the three-wire system developed a fault which so damaged the cable that it became parted, a certain part of the system might be working with only the full pressure across the outers to deal with the load. In this case, unless the load was balanced equally on each side of the system, serious damage might be incurred by installations connected to that side of the system on which the load was lightest, owing to excessive pressure. The leak, being ascertained by the testing appliances at the generating station, may be discovered and removed long before the cable would become burned through or affected in such a manner as to interrupt the supply.

In making joints on concentric conductors while alive, care is required to guard against short circuits, but not more than ordinary care. Ordinary care, however, is not a natural acquirement of the average British workman. Both outer conductors require to be cut and re-jointed when a tapping is made from the centre conductor. A concentric cable is cheaper than three single conductors, and takes up far less space. Electrolysis troubles arising out of leaks setting up between the conductors, are reduced to a minimum, provided the outer conductor of the cable is worked at earth's potential, and this is the general rule. Earth leaks are hardly possible owing to the fact that with the outer conductor being worked at earth potential, any leak from the inner conductor or conductors must pass to the outer before reaching earth, and in doing so a short circuit will be formed, which immediately operates the section-box fuses and disconnects the faulty section from the source of supply.

The fact that defective insulation in a concentric main produced a short circuit and not, perhaps, a small leak, means that this section of main consisting of the three, and not only one or two wires, is in nearly every case completely thrown out of action until the defect is remedied, and this is a matter of serious inconvenience to consumers' supply. Cases have been known in which, although a short circuit has existed between two conductors on a triple concentric distributor, the supply has not been interrupted on any of the mains. This has occurred when the two inner conductors which have constituted the positive and negative mains on a three-wire system have short-circuited, and the fuses on only one of the conductors has blown in the section-box. Suppose the fuses on the negative conductor had blown, the negative main would

be in parallel with the positive, being fed from the positive through the short circuit; both mains would therefore be positive to the neutral wire, which would have to bear the full load of the supply on the main. Unless consumers supplied by this defective main used apparatus which required the pressure across the outers, or complained of defective pressure, this defect might not be noticed until the meter inspector found something extraordinary in the readings of the meters connected to the negative side of the system. Fortunately, however, such a defect very rarely occurs, the general rule being that if a short circuit occurs between any two conductors, all three become short-circuited.

From the point of view of the efficiency of central station supply there is no doubt but that a triple concentric system can be maintained in a nearer state of perfection than a system consisting of single conductors, for the reason that as a rule any defect in insulation between the conductors sets up a leak, which does not cause current to flow along the sheathing or through earth, but is contained within the cable itself, thus no electrolysis of the metal sheathing will be produced and the whole damage is confined to one spot. Whereas with a system of single conductors small leaks may remain undetected for a considerable time, and have very destructive electrolytic effects upon the whole system. This specially applies to large systems when it becomes practically an impossibility to take frequent insulation tests of each section of the system.

It would appear that, looking at the matter from a practical point of view, the whole question should devolve itself into, what is the best system to adopt to guard against electrolysis (the prime evil) and mechanical damage? Should not the risks incurred, due to defects in manufacture and jointing appliances, be left entirely out of the question? As with an experience already obtained on these points the time should be very near at hand when it may be safely assumed that accidents due to such will be very few and far between. Judging the matter from this standpoint, the adoption of a triple concentric system with an insulating outer sheathing laid on the solid system in cast iron or stout wooden troughs seems to answer the question.

It has not been the intention in this paper to attempt to discuss methods of laying out systems of distribution for supply undertakings, such a subject requiring far more time and space than is allowed for this paper, if dealt with even in a very incomplete manner. The chief object has been, in the first place, to draw some amount of comparison between the systems at present mostly in use, and, secondly, to give a few particulars on practical points connected with them, which may be of use to engineers interested in this often neglected but all-important branch of an electricity supply undertaking.

Professor Jamieson.

Prof. ANDREW JAMIESON said it was now evident, that electric light engineers had arrived at much more practical and sensible methods of laying down and connecting up their distribution mains than was the case a few years ago. He remembered telling one of the Pioneer Directors of the first electric lighting company for London, on hearing how his firm were laying down their mains, that in less than six months

Professor Jamieson.

they would have serious trouble and expense as well as cause public vexation, disappointment, and mistrust in their system. He suggested that the Company should engage an experienced submarine cable electrician and engineer, who had dealt with testing and laying of the "shore ends" of submarine cables. The pioneer replied that they required no such highly paid labourer. The consequence was, that their whole underground system had to be abandoned. From the beginning of 1874 to the Midsummer of 1880, he had more or less continuous experience of the difficulties in connecting the "shore ends" of submarine cables with the town offices of many cities by land lines and by underground cables, on the Brazilian coast as well as between England and India, etc. At Pernambuco, the Western and Brazilian Telegraph Company used aërial lines, whereas the Brazilian Submarine Company employed insulated lead-covered underground wires. Both were subject to interruptions due to faults, but the latter was the less frequently disturbed. At Gibraltar the conveying of heavy cannon along the road caused subsidences, and the late Mr. De Sauty (of 1865–66 Atlantic Cable fame) erected hollow pillar boxes at convenient distances apart, along the side of the underground cable route, for the purpose of facilitating the holding of, connecting, testing, and disconnecting, the ends of the cable sections, as well as of substituting fresh ones, in a similar way to that which Mr. Wordingham recently introduced into Manchester; and as had just been erected for the Glasgow Tramway feeder cables. The Island of Malta was chiefly composed of soft sandstone rock, not unlike "Bath-brick," and there they hewed miles of trenches about two feet deep, into which they put several iron-armoured light cables, for connecting the different shore-ends with the Valetta Telegraph Central Office. There, the soft stone was so porous, that the hot summer sun combined with the periodical sirocco winds caused the guttapercha core to become "perished," *i.e.*, hard and brittle, and in some instances the guttapercha turned from a natural dark rich brown to a whitish sickly yellow colour. But all these difficulties had been overcome. For example, at Aden, they had recourse to watertight cast-iron junction-boxes placed below high-water mark, with watertight pipes leading therefrom up to the Telegraph Office. These pipes were always kept full of water, and consequently the guttapercha cores were preserved just as well, as if they had lain at the bottom of the sea, and the requisite high-insulation resistance was maintained.

Mr. Ward said that "Mr. Sydney Baynes appears to have been one of the first electrical engineers to recognise the importance of protecting ends of cables in this manner." This might be so? But the speaker remembered being called in by the Greenock Corporation as consulting electrician in 1883, when they were the second, if not the first, to adopt the privileges of a "Provisional Order" under the 1882 Electric Lighting Act. He was very glad to be associated with Mr. E. W. Beckingsale as the contractor, who also recognised at that early date the full importance of protecting the ends of cables, and took out at that time the first patent (he believed) for underground cast-iron junction-boxes. The stranded conductor of the cables was first insu-

Professor Jamieson.

lated by a dielectric of thread, saturated with a highly insulated mixture, and then lead-covered. The awkward property of this porous dielectric was, that water, damp, or moisture, percolated along the core whenever the lead covering was cut, so that the ends had always to be sealed as soon as possible in Greenock, that "Rainopolis" of the West. Mr. Beckingsale used a sleeve of insulating material (drawn tightly over the ends of the conductor, the bared part of the dielectric and on to the lead) to keep the moisture from creeping through, and along the surface of the dielectric to the lead sheathing, as well as for covering joints. (See this Journal, vol. 18, p. 122: Discussion by E. W. Beckingsale on "The Insulation Resistance of Electric Light Installations." Paper read by Professor A. Jamieson, January 24, 1889.)

Mr. Ward advocated the adoption of a corrugated ebonite bush for preventing the insidious creeping back of moisture along the gun-metal terminal sockets of the "Baynes box." Ebonite when good, new and freshly turned, or machined, was an excellent insulator, but when exposed for months, or perhaps years, to atmospheric changes (more especially to light and heat), it deteriorates. He would suggest a trial of a compressed hard compound of selected mica tailings, of a similar nature to that of the "Brooklyn" and "Globe" insulators for insulating span-trolley wires of the electric tramways. For preventing the electric osmose action, nothing surpassed several coats of the best elastic varnish, when properly applied. Should this coating become dirty at any time, it could easily be cleaned with a cloth and wood naphtha.

The persons who are to be ultimately placed in charge of the maintenance of distributing mains, should (if possible) be present from the very commencement to the finish of the laying-down operations. For, with all the skill "of fault-finding" by electrical testing, there was still ample room for the use and application of careful observation, when combined with copious notes and illustrative sketches taken during the laying down and the covering up of these cables. If all the circumstances and conditions were duly noted, the position of a fault in a section of cable might be frequently denoted by knowledge of these and the application of common-sense, combined with simple electrical tests; since, neither the specification, nor the manufacture of the best types of cables by the best makers, gave cause for apprehension of weaknesses. Faults nowadays generally arose from hurry and carelessness in the first installation, or in repairing the cables.

The speaker would have been pleased to learn something more from the author regarding the working, additions to, average resistance of, and maintenance bill for, the bare copper strip conductors, which were first devised by Col. R. E. Crompton, and reported upon by him (the speaker) to the Glasgow Town Council more than a dozen years ago.

Mr. Burnet.

Mr. C. D. BURNET said he had been in Glasgow two months previously, and by the courtesy of Mr. Ward had had opportunities of seeing the arrangement of the cables at one of the feeding points of the Glasgow mains, which had been fitted throughout with the appliances designed by Mr. Ward. The whole arrangement did him the

greatest credit. No single point, however minute, appeared to have been overlooked or neglected. The only thing that was slightly against them at present was the initial cost of the boxes, but this was far more than counterbalanced by the facilities which they afforded for disconnecting for testing purposes, and he (the speaker) looked upon them as indispensable where triple concentric cables were used. By means of these boxes Mr. Burnet was splitting up the principal districts in Carlisle into sub-districts in the area supplied by triple concentric cables. On several occasions workmen had driven picks through these, and had thus completely short-circuited the cables. This was preferable, however, to the driving of the picks through the armouring and lead-sheathing as sometimes happened, so that when the barometric conditions altered; the water in the surrounding soil worked into the cable and a short-circuit was the result. That necessitated the localising of the fault, which occupied valuable time. If a district is controlled by suitably arranged fuse-boxes the faulty length will be cut out, or a length of (say) three-quarters of a mile of cable will be completely cut off automatically, and the fault should be localised in a very short space of time, probably within an hour of the occurrence. This is not so with the ordinary boxes supplied with the cable. It will take several hours (three or four perhaps) if a large district has to be dealt with, before the length containing the fault can be cut out; and the consequent inconvenience to consumers is very serious. Single cables laid on the solid system were being used in any extensions in Carlisle. In making this change he had been influenced principally by the trouble which is likely to occur from electrolytic action on the lead-sheathing of the cables laid direct in the ground; secondly by the extreme likelihood of such action taking place between the armouring and the lead of the cables themselves; thirdly by the wish to guard against chemical action; and fourthly with the object of gaining time in case of a breakdown, single cables giving more warning than triple concentric. In Carlisle the Corporation had entered into a contract with the Tramway Company to supply current for traction purposes. The negative bar is earthed at the station, as also is the middle wire of the lighting systems of mains. If the lead-sheathing in all the cables was continuous throughout, he feared that the breaking of a bond in the rails of the Tramway Company, if it should occur, would rather tend to make one regret that this was so. He might be quite wrong, but he thought that, if the lead-sheathing of a long cable were cut at intervals in order to connect services to consumers, and there were a tendency for current to flow along this lead owing to some outside cause (the boxes in the first place having been laid with this in view, with a space of about half-an-inch in all cases between the lead of the cable and the iron work of the box), an opposing E.M.F. would be set up between the lengths of lead, the sum of which would be in proportion to the number of interruptions in the lead, with the result that the current would be more likely to travel along some other conductor, whereas one faulty bond in the lead would probably burn out and result in serious damage to the cable if, in the alternative case, the lead were bonded. In conclusion he wished to congratulate Mr. Ward on his exceedingly useful paper,

Mr. Burnet.

Mr. Burnet. and the comprehensive and able way in which he had dealt with the subject.

Mr. Scott. Mr. J. Gray Scott agreed with Mr. Ward that due attention was not paid to the question of mains. If for no other reason than that of the amount of capital expenditure in them, they should receive greater consideration. He had been very much interested in the disconnection box shown by Mr. Ward. In one part of his paper Mr. Ward had mentioned that owing to the deficiencies of the articles supplied by manufacturers, it had been necessary for engineers to design boxes of their own. He (the speaker) had also had to do this in Leith, and he had met with success. He should like, however, to have more information regarding the cost of the very elaborate box shown by Mr. Ward. He noticed that Mr. Ward favoured plumbed joints. In his experience such joints had presented difficulties, probably on account of the carelessness of the British workman. He found that a gland box could be fitted much more satisfactorily. Mr. Ward had also touched upon a very important point, viz., fusing the network. He was not aware that this was done in Glasgow, but it was interesting to hear it because he also did it in Leith, though it was a much debated point. The diagram by Mr. Ward was very interesting, but he questioned if it could be thoroughly safe, should the earth take place in any part of the network. The arrangement would no doubt work satisfactorily, but he thought it was very difficult indeed to fuse a network so that the fuses will go at the precise place and moment desired.

Mr. Ward had dealt with single *versus* triple concentric cable. That was a very important point. He thought the latter were more easily handled and were cheaper. With regard to electrolysis, he had had absolutely no trouble in this respect. He had lead-covered cables, and he was careful to see that the bonding was done efficiently and throughout the whole system, and, moreover, his Department had been successful in obtaining the permission of the Water Trust to bond the lead of their cables on to their water mains.

Mr. Chambers. Mr. G. K. Chambers said: The word "electrolysis" frequently occurred in Mr. Ward's paper, and the author referred to the possibility of corrosive action on the lead-sheathing due either to the action of external stray currents, such as tramway return currents, or (on account of the failure of the dielectric) to the passage of current from the copper conductor to the lead-sheathing and so to "earth." The speaker had not been able to find in the paper that the author mentioned having experienced any failure of cable due to electrolytic action on the lead. He constantly referred to the necessity of guarding against it, and the difficulties of doing so, but he did not quote a single instance of trouble having arisen from this cause. It appeared to be obvious from this, either that Mr. Ward had managed to surmount the difficulties, or else that the danger was one which existed in his imagination. The speaker was constantly travelling about the country, and had every opportunity of hearing if any trouble of this nature should arise, and there was little doubt but that if it occurred in the case of any cable manufactured by the Company he represented he would not be long allowed to remain in ignorance of it. In point of

Mr. Chambers.

fact he could not quote a single instance where lead-sheathed cables had been damaged in the way mentioned when proper precautions had been taken. These precautions were of the simplest character, as they solely consisted of the continuous bonding of the lead-sheathing across boxes, etc., so as to make it electrically continuous throughout its whole length, and its efficient earthing at a point or points, the position of which must depend upon the local conditions. When the enormous quantity of lead-covered cable in successful use in this and other countries, especially in traction work, was taken into consideration, it was obvious that the cry about electrolysis is one which is by no means founded on practical results. In point of fact, the engineers and manufacturers who had most to say about electrolysis of the lead were those who were not users or manufacturers of that class of cable, and consequently had no practical experience in the matter. He thought Mr. Ward had overrated the difficulties of putting down earth-plates. All engineers knew of this difficulty when the plate had to carry any considerable amount of current, as the fact of the current passing from the plate to the surrounding soil tended to dry out the moisture from the latter and thus practically to insulate the earth-plate. In the case, however, of earthing the lead-sheathing, the currents to be dealt with are either exceedingly small, or are only on for a very short interval of time. From practical experience the speaker could say that an earth formed in the way Mr. Ward described, viz., by planting a length of cast-iron pipe, forms an earth which was quite efficient for this purpose. He agreed with Mr. Ward that cast-iron is as good as copper, only he had usually found it advisable to surround it with coke.

The question of fusing feeders and networks was an exceedingly interesting one, and opened out a very large field for discussion. Whilst believing in a system of fusing, especially when the load on the network is comparatively light, he thought it quite possible to overdo it. The system which chiefly commended itself to the speaker was that of fusing distributors at the feeding points and dividing up the network into a number of sections, each of which was fed by a feeder, and connecting those points where the sections meet through light fuses. The advantage of this method was that a perfect balance would be kept throughout the network, but should a fault develop on one section the light fuses which connect it to adjacent sections would immediately blow, thus insulating the section in which the fault had occurred. The heavy fuse at the feeding point protecting the particular distributor on which the fault had occurred would be the next one to blow, so that the amount of cable thrown dead would be comparatively small. With regard to the fuse-box which Mr. Ward had described this evening, the details seemed to have been exceedingly well thought out, and the box should be in every respect—but that of cost—an admirable one. The cost of such a box must be very high, and it was to be regretted that Mr. Ward had not given any figures for purposes of comparison. It certainly appeared that if an engineer were to go to so great an expense he would be far better advised to spend the money on over-ground section pillars. Mr. Ward inferred

Mr. Chambers.

that cable makers did not give sufficient attention to the manner in which boxes were made, but this was scarcely fair. The average cable specification consisted of about forty pages of General Conditions, three or four pages giving full particulars of the cables, method of manufacture, thickness of dielectric and lead-sheathing, where used, insulation tests, etc., etc., and in some obscure corner would be found the statement that "this Contract also includes the supply of thirty or so disconnecting boxes." Usually no particulars were given as to the size the boxes are to be, the distance between poles of different polarities, or any other information whatsoever, and it naturally followed that the manufacturer, in his anxiety to keep on equal terms with his competitors, would offer to supply the cheapest box which would do the work. If he did not he would probably lose the order. Mr. Ward, in speaking of lead-sheathed cables, referred to the possibility of pin-holes in the lead-sheathing. This pin-hole theory had been exploded for a long time, and with present-day methods of manufacture pin-holes had become an impossibility. In conclusion, he would like to ask Mr. Ward whether he did not think that engineers would be better advised to lay down lead-covered cables, of which the life was only limited by that of the lead-sheathing, taking those precautions against corrosive action which experience had proved to be absolutely reliable, rather than to install cables with an insulating outer sheathing such as he (Mr. Ward) mentioned, through which the conductors might sink in course of time, should their temperature be appreciably raised by a slight over-load, or even when working under normal conditions. As to whether such material would prove to be of a durable character time alone could show.

Mr. McWhirter

Mr. W. McWhirter, referring to Fig. 1, said he could not agree with the use of ebonite glands, as it had been known to telegraph engineers for many years that although ebonite when newly done up was almost the best insulator obtainable, yet the surface soon changed to such a degree as to allow of considerable leakage, and with the higher voltages required in electric lighting, etc., no doubt it would deteriorate rapidly. In his opinion the trouble due to leakage between conductor and sheathing could only be prevented by the use of some form of oil gland on the principle of the Brooks system, and he believed that there was no very great difficulty in designing such an arrangement. He would be glad if Mr. Ward could give them any idea of the resistance to earth of the pipes he used for earth-plates. He was afraid this would be found extremely variable, and much higher than might be supposed. He was pleased that the Water Commissioners of Leith had shown themselves so sensible as to allow the Electricity Department to earth on their water-pipes. He felt sure that this was the most certain way of protecting pipes not only from electric-light-, but also from traction-, currents, and so avoiding damage due to electrolysis. The remarks made by Mr. Ward as to the failure of manufacturers to meet the requirements of municipal engineers had been replied to by Mr. Chambers. He (Mr. McWhirter) would, however, like to point out the waste of time and capital which manufacturers might needlessly make in attempting to meet such requirements, seeing

that our municipalities very shortly hoped to be in the position not only to supply all their own electrical apparatus, but also whatever may be required by the consumers. The Corporation of Glasgow were now promoting a Bill to give them powers not only to supply electricity, but to manufacture, buy, and sell all and everything required by consumers; this fortunately had not yet become law, and probably before it did the poor electrical manufacturers and contractors who also happened to be ratepayers might have something to say about it, or possibly the Corporation might see fit to pension off those unfortunate individuals whose services would no longer be required. Mr. McWhirter.

For many years he had pointed out the risk of using cables where the whole protection depended upon the lead-sheathing, and he was glad that central station engineers were now inquiring into the matter, which they certainly ought to have done more fully before sinking such a large amount of capital in cables so protected. He did not agree with Mr. Ward that it was impossible to get cables which would be free from the faults he had enumerated. It was only necessary to look at the splendid work done in submarine cable work to see that manufacturers were quite able to supply such material up to any required standard.

Mr. A. ADAMS (*communicated*): Mr. Ward's paper gives rise to many interesting points, and while I agree with his conclusions regarding several of these, there are others where I do not agree with him. The systems of underground mains have not received the attention they should have received, and I agree with the author that the success and suitability of one system is a matter of opinion among engineers, just as the wiring rules of one engineer differ from the wiring rules of another engineer under similar conditions. I am of opinion that the sealing up of the ends of the cable can be done quite satisfactorily with tape or a rubber sleeve pulled over the cable end. It is a cheap and neat way of doing the job. With regard to fusing, I agree that it is necessary and proper to fuse the feeder where it joins the network, but fusing the network is a very expensive item, and appears to me to be a weakening of the system and to give rise to a great deal of trouble. I do not think the use of cast-iron manholes is justified as against a good brick or concrete manhole. The space required inside the manhole of course depends upon the system adopted, and the fusing of the network also depends upon the system adopted. Mr. Adams.

Referring to the different systems of mains, I think the "draw-in" system claims many advantages over any other system. A fault can be traced very easily without interfering with the supply in any way, and it is a mistake to say that when branches are connected to the mains it is no longer a draw-in system, for after a fault is traced to a main it can be located to a section between the branch joint-boxes. These can be picked up and the faulty piece of cable between the two joint-boxes withdrawn, repaired, and connected up again, and this can be done with the mains alive, and without interfering in any way with the supply if mains are three separate conductors. There is no chance whatever of the conductor being fused to the iron pipe. This would only occur if there was a short-circuit or more than one fault on the

Mr. Adams. system. There are other advantages that I could name in favour of the draw-in system. I think I am correct in saying that the parting of the neutral wire would only take place with a tail end, or where the network is supplied with one way only. As a rule the mains are connected in a ring. I do not think that concentric mains are cheaper than single if you take into account the iron manholes, fusing of the network, and expense of jointing, and of joint-boxes. Three single cables with brick manholes is, to my mind, a much more satisfactory job, and takes up no more room, when you take into consideration the space occupied by the tee-joint-boxes in a concentric system.

Mr. Henderson. Mr. Charles A. Henderson (*communicated*): With regard to the disconnecting boxes described, it would be interesting for the sake of comparison to get the price of the box and fittings complete, and also to hear if trouble has been experienced by having a cover which is so easily removed by any person of an interfering nature. I have been surprised that it has been thought advisable in Glasgow to have four 4-way disconnecting boxes at the four corners of two intersecting streets instead of one 8-way box. It is usually found cheaper to lay the four extra crossings that are necessary and have only one large box, sometimes with two covers, and I would like to hear the arguments in favour of four 4-way boxes. Mr. Ward has, I think, omitted one of the most serious faults of strained copper strip, viz., the phenomenon of "jumping" when heavily loaded suddenly, due to faults. I have seen on several occasions strained strip, which has been feeding a fault, "jump" so badly as to release itself from the strain insulators and fall to the bottom of the culvert. In one case I saw all the strips of a three-wire net-work thus affected, and the result was worse than the original fault. I certainly agree with Mr. Ward when he advocates removing the possibility of electrolysis by using an insulating sheathing for cables, but he has forgotten altogether, in comparing different systems, that of three-core cable, which is cheaper than and like triple concentric—usually either all right or you have a dead-short in all three conductors. It is very much easier, safer, and cheaper to joint, for no fittings are required, and where the joint is a "T" it is not necessary to cut the copper of any of the conductors, an ordinary "T" joint on each core being all that is required. In advocating three-core I would like to point out that with a tail end of triple concentric, and a large motor load at the far end, you must disconnect the cable to make a joint, which means several hours, but with three-core the joint can be made safely by the average jointer while the cable is alive.

Continuation of Discussion, February 11, 1902.

Mr. Newington. Mr. F. A. Newington (*communicated*): This paper deals with a very interesting and important subject. The author is evidently a strong believer in triple concentric cables, and deals chiefly with the troubles arising from lead-sheathing. This for alternating currents is admirable, but I must say that I do not like it for continuous-current work. Most of the difficulties mentioned are directly caused by the lead-sheathing. As regards the continuous earthing of the neutral conductor, I am afraid that this would much increase the difficulties of

distribution. By all means connect to earth in several places, but each place should be under complete control. I would suggest connecting the lead-sheathing to the water mains. This cannot do any harm if properly and thoroughly done, and will probably do good. The water authority should not raise objections. Mr. Newington.

Fusing.—I agree with the author that these are necessary evils. I think it doubtful whether it is necessary to fuse at feeding points. With a draw-in system it simplifies matters only to fuse the distributing mains at mid-way points between feeders. Any ordinary short-circuit on distributing mains should clear itself without doing much damage. A short-circuit on a feeder would necessitate that feeder being switched off at the generating station and then the fuses in the distributing mains would act, cutting off the supply in that district until the feeder was disconnected. This very much reduces the number of fuses. The arrangement shown on diagram Fig. 5 apparently does not prevent a district being cut off if a feeder breaks down; therefore, to me, feeder fuses do not appear to be of much use.

The arrangement of joint-boxes, manhole-boxes, fuses, etc., shows a great deal of careful thought and design, and I hope they will overcome the troubles which led to their use. I should like to ask the author whether he has ever found the conductors drawn out of the clamping pieces due to contraction of the cable in cold weather.

Dealing generally with the four systems mentioned on the first page, the most important points in a system of electricity supply mains are, I think—(1) Reliability of supply; (2) simplicity; (3) cost of up-keep; (4) cost of installing. With a draw-in system using separate insulated cables in earthenware or bitumen compound ducts, a fault on a cable can hardly develop into a short-circuit. The great trouble with this system is that all insulation at present known is more or less porous, and on account of osmosis moisture gets to the negative conductor, and the insulation resistance falls. We require some better material for insulation. It might be advisable to use lead-covered cable for the negative conductor, but I rather hesitate to try this on a large scale. Earthenware casing appears to have some curious effect on the insulation, but on the other hand it is in itself an insulator. I cannot agree with the author that a draw-in system soon ceases to be such on account of branches. At every branch a box should be provided so that it can be disconnected. Supposing a fault occurs in an iron pipe as described in the paper showing signs that the conductor had fused to the pipe, it is possible to open the ground at the point and examine the pipe, and if necessary cut out the damaged part. Bare copper strip in concrete culvert gives remarkably little trouble if the strip is strained and all the insulators can be kept clean. At the same time I think that the usual arrangement of gripping the strip is not good, far too much depends upon one or two set screws. There is another disadvantage to strip in culvert, and that is the great force exerted by attraction between two conductors of different polarity in the event of a sudden rush of current. I have made some rather interesting experiments on this, and find that with two conductors placed three inches apart, if a short-circuit occurs and there is a sudden rush of current of say 5,000 amperes (which I think

Mr. Newington.

quite a moderate estimate for the first second or so), there would be a pull of about 200 lbs. on each insulator. This means that in the event of a short-circuit happening, the insulators carrying the strip will probably break and let the strip down on to the bottom of the culvert. I have found that with the strip not strained and the insulators close together, there is a very large amount of leakage with a three-wire system with the middle wire at earth potential. I have not tried a cast-iron culvert, and I do not think I wish to do so.

The various chances of breakdown described in the paper do not apply to a draw-in system. I think, therefore, that as regards reliability of supply and simplicity the draw-in system with insulated cables is the better. The insulation breaks down in time, but the conductors can be re-insulated. One of the disadvantages to a draw-in system is the cost of inspection of the manholes at fairly frequent intervals, and apparently this applies also to the solid triple concentric system described. The cost of up-keep may perhaps be higher with a draw-in system, but probably the first cost of the other is greater.

Mr. Chamen.

Mr. W. A. Chamen then said that the information Mr. Newington had given about the side-pull on supporting insulators with bare copper strip was most valuable, and he was not aware that up to the present any one else had made experiments with regard to the actual amount of stress on such insulators. They knew in Glasgow that a tremendous amount of force was exercised, because on an occasion when the copper strip had come in contact with the roof of the cast-iron culvert the strip had become bent in beautiful horizontal festoons between the insulators just as if it were soft cord. A point worth noting with copper strip was that one could get a real short-circuit, but with concentric cable, although the conductors are in such close proximity, a real short-circuit seldom or never occurred. Arcs would often form between the conductors, and go on burning away for some time before enough current would pass to blow the fuses. With regard to the question of electrolysis, he would like to mention that in the early days of the Kensington and Knightsbridge Company lead-sheathed cables were used to connect consumers. These cables were run through walls of premises, and it was found that they were always going wrong in the walls. This was at first ascribed to the chemical action of the cement, but in the end Mr. Miller discovered that the cause of the trouble was something quite different. Nobody paid attention to the ends of the cables, and what happened was that the current was leaking over the ends on to the lead, passing along to the walls and there getting to earth and corroding away the cable. What they talked of now in Glasgow as electrolysis was really quite a different thing; it was not really electrolysis but fusion. He thought Mr. Ward had brought this point out very clearly. They might get the lead-sheathing of the cable in contact with the circuit through some accident, and if the sheathing was insulated in bitumen the current might have to go along until it could find a place weak enough to allow it to jump to earth; and if the cable were laid in cast-iron troughs it would find such places to come out at and would burn holes in the lead at these places. That was their great trouble, and when

Mr. Chamen.

they talked about bonding all these cables and boxes, what they meant was putting in a good solid bond which could carry a large current. He thought Mr. Ward had made it clear in his paper that, with regard to jointing, they did not like wiped joints. Mr. Scott had said that Mr. Ward was in favour of lead wiped-joints. That was a thing they had had to give up, and their joints now were all made with compound. Mr. McWhirter had spoken about municipal trading, and seemed to think that the Corporation were going to take all the work out of the hands of electrical contractors. He seemed to be greatly worried about a clause in an Omnibus Bill which the Glasgow Corporation were trying to get passed. What they wanted was to be able to hire out motors and consuming devices for the convenience of consumers, and by so doing they would be greatly benefiting wiring contractors. The wiring contractors were the Corporation's best friends, and Corporation engineers always liked to see them busy. With regard to the feeder fuses, it had always been his idea that feeders ought to be coupled to a common network. He had hoped to get over the difficulties of this arrangement by means of non-return cut-outs at the feeder points which would immediately break circuit in the event of the current trying to back down a feeder from the network owing to a short-circuit in the feeder itself. It was, however, a troublesome matter, as a manhole was not a good place for an automatic switch, which might stick and refuse to work on account of dirt or corrosion through damp. It was probable, however, that the common network idea would have to be departed from for other reasons, and that a city would have to be divided into different districts of networks each supplied either by one feeder only, or by a limited number of feeders such as two or three, and in this case it might be better to do away with the feeder-fuses so far as the feeding-point was concerned and to rely upon the distribution-fuses only at these points.

Mr. Field.

Mr. M. B. Field wrote that he was unable to be present, but sent two sample cable joints. They were 6,500-volt three-phase cables, and illustrated the method of jointing by means of lead sleeves and filling with paraffin. In the samples sent, two short lengths of cable were taken and quickly jointed together; as they were not securely held, the joint did not come central inside the lead sleeve. This did not really signify, however, as there was $\frac{1}{4}$ in. of paper between the copper and lead, which is the same as the insulation inside the cable itself. The unusually heavy lead sheath on these cables would be noticed, the thickness being $\frac{3}{16}$ in. The coppers were jointed by means of copper sleeves slipped over the butted ends of the cores and soldered. This was, of course, very much against English ideas and practice. It was, however, the system upon which the Tramway Department's cables had been jointed throughout, and at present no ill-effects had been noticeable therefrom. Such a method saved an enormous amount of time in jointing. Each core of the cable was insulated with $\frac{1}{8}$ in. of paper. The three cores were then twisted together and the whole surrounded by another $\frac{1}{8}$ in. of paper before the lead sheath was applied.

Mr. S. Mavor.

Mr. Sam Mavor said: The arrangement by which underground mains and feeders were connected in Glasgow in spacious cast-iron

Mr. S. Mavor. chambers seemed to him to be admirably carried out. India-rubber insulation was surely out of the question for underground cables of large size owing to its cost and its deficiency as regards durability. It was surprising to hear Mr. Newington's frank acceptance of a type of cable whose insulation is admittedly perishable, and his willingness to draw in these cables with the future prospect of having to draw them out again to reinsulate them. The better policy was surely to adopt cables of a type which under normal conditions would be permanently durable. Mr. O'Gorman showed him, a short time ago, a very interesting cable devised for high-tension work. It was insulated in several layers. The innermost layer was impregnated with an oil of relatively great electrostatic capacity, and each layer successively towards the outermost had a smaller capacity, the result being that the stress was more uniformly distributed than in a cable with homogeneous insulation. It was claimed that the advantage gained by this cable was analogous to that of a wire-wound over a solid gun. His own very strong opinion was that triple concentric lead-covered cables were the best for underground distribution. It ought to be remembered that it was only within recent years that cables of this type in larger sizes had been manufactured, and the machinery for such work was also only of recent development, so that it was only fair to expect that such improvements would be made as would increase the reliability of heavy lead-covered cables. He quite agreed with Mr. Chamen that what they suffered from in Glasgow was not electrolysis so much as fusion. The advantages of triple concentric cables might be summarised as follows: they are self-contained; there are fewer cables to handle; the cost is less; the space required is less, and therefore there is less liability to damage; there is less bonding required, and if this is properly done he felt sure the troubles from electrolysis would not exist; and they were self-testing in a way that separate cables were not. He thought that efficient earthing as well as bonding ought to be carried out at every feeding point.

Mr. J. Brown. Mr. James Brown said that the importance of the matter under discussion was easily seen when it was remembered that mains represented practically about 50 per cent. of the capital outlay of an electric supply undertaking, and that a fault occurring in the mains might cause the whole supply to be shut down. Mr. Ward had called attention to the various systems of supply and to various details in connection therewith, as well as to various kinds of faults which might occur. In the town with which the speaker was connected the feeders and mains consisted of three separate armoured cables laid direct in the ground. The middle wire was connected at the station through a recording ammeter and resistance to earth, while the positive and negative 'bus-bars were connected through static voltmeters to earth. By this means they readily noticed any fault on the mains as well as the time the fault actually occurred, and by the voltmeter readings they gained a rough idea as to the magnitude of the fault. It was interesting to note that most of the faults had generally been traced to terminal ends in manhole-boxes, consumers' fuse-boxes, etc., and were almost without exception on the negative conductor, and due to the

reasons Mr. Ward had described. As regards which system of mains is the best for any purpose, a mixture of all systems, as seems to exist in Glasgow, was certainly not very desirable. Mr. Ward had described a very interesting disconnecting manhole-box which was being used in Glasgow. He would be glad if Mr. Ward could state in his reply who were the makers of the manhole-boxes described, as well as the cost of each part, iron box with lid, porcelains and terminals, etc. Mr. J. Brown.

Mr. J. M. MUNRO said he condoled with Mr. Ward in the task which was set before him of combining so heterogeneous a collection of cables as that under Glasgow pavements into an efficient system suited for the pressures now used and having standardised fitments. But he congratulated him on the experimental data thus put at his disposal, as well as on the very large measure of success which now had crowned his efforts. Mr. Ward had not said much, if anything, regarding the relative costs of the various systems he described. It might add to the value of his paper if, before publication, he would add to it a table of relative costs, not of the cable alone (that could be got from price lists), but of each system laid complete, of common sizes, in the normal Glasgow street. Those approximate prices would assist members in the comparison of one system with another. It would be interesting also to know how the author first became convinced that, for the protection of lead tubes, a cheap pitch compound would serve for filling troughs as well as the more expensive bitumen so long considered necessary by electricians, though not by plumbers. Had he observed any action of the pitch upon the lead or upon cables not lead-covered? Mr. Munro.

The speaker was the more interested in the continued protective and insulating qualities of those compounds, because in the early days of the industry, when people proposed odd things cheerfully, he designed, for some underground wiring, a system in which a tube of bare copper, soldered and coupled end to end, was carried by insulators in a concentric cast-iron, or adamantine, or concrete, pipe, which was to be filled up solid with bitumen. The idea in making the first laid copper tubular was that more copper could be pulled in afterwards as wanted, or, if the worst came to the worst, a V.I.R. cable could be drawn through. He had been afraid to trust anything but special bitumen compound, and the price of that had proved too high for the money to be spent upon the work. Mr. Ward described excellent methods of making connections between lead-sheathing, brass couplers, and iron boxes; but did not those metals, thus connected in damp soils, set up some local electrolytic corrosion wherever lead-coverings were exposed? With regard to pin-hole faults in lead-coverings disclosing themselves after a time in cables which under test had shown no evidence of them, might they not sometimes be due to electrostatic discharges arising from electric surgings accompanying lightning, or from opening of motor circuits, or even from condenser resonance action of the cables and lead-coverings when feeder fuses blow? He admired very much the system of feeder connections and disconnecting boxes illustrated by Mr. Ward in Fig. 5. If he could carry this a step further and join up

Mr. Munro. the smaller sections of his distributing system on the same principle, he would have usefully solved a troublesome problem.

Finally, he asked if Mr. Ward had made trial of two double concentric distributing mains laid parallel in troughs,—a positive inner and "mid" outer in one cable, and a negative inner and mid outer in the other. If these were lead-covered the coverings would of course be inter-connected at intervals, but such cables would preferably have insulating coverings. In either case they would be laid solid with, if possible, some plan for keeping the pitch from actual contact with the cables and protecting them when the pitch was intentionally broken to get access. As the cost of insulation increased with diameter, the price of such cables would not be very much above that of triple concentric, and they would combine most of the advantages of triple concentric with those of single wiring. In the event of a burn-out, only one side of the three-wire supply would be affected, and, in distributors, connections for consumers taking less than 25 amperes could be more cheaply made. Also the maximum P.D. between conductors in a cable would be halved. He did not offer this as a carefully thought-out, still less as a novel, plan, but as a suggestion of the moment, and would be glad of Mr. Ward's criticism of it. He himself had been rather fortunate with his underground wires: once down they had given but little trouble. He had had trouble with certain lead-covered jute impregnated cable. This was laid, not solid, in a pitched trough, with a cover secured by a few nails. Some faults developed by corrosion of the lead near the nails. As the trough was wet, inside and out, all over, he did not ascribe it to terminal leakage to the lead finding earth by the nails, but to local action on the lead in touch with, but not even scratched by, a few carelessly driven nails. Elsewhere faults occurred from nothing more subtle than a pavior's pick. This freedom from breakdown he did not attribute to any phenomenal care in the choice or laying of these cables. It was partly a result of the low pressure used in the majority of them, but due chiefly to the fact that they were on isolated installations, where all the conductors could be kept insulated from earth. There was much to be said in favour of earthing the mid-wire, but some modifications in the manner of it were advisable. In any case it brought with it troubles and dangers, not only to street cables, but to interior wiring and indoor earth connections. He thanked Mr. Ward for his paper, so full of useful practical detail.

Mr. H. A. Mavor. Mr. H. A. MAVOR said that there were many points that one might talk about, but they had been very well taken up. One point that struck him was the leading of cable into boxes. A method adopted by his Company sometimes was an extremely simple one. It was to lead the cable into the box through a pocket in the side of the box, and to fill the pocket with molten metal. With regard to the troubles arising from electrolysis, there was a gradual growth of a wiser view in favour of earthing the neutral conductor throughout, and he was sure that that would obviate many of the most serious difficulties in this connection. As a manufacturer he was much interested to see the carefully thought-out junction-boxes shown by Mr. Ward as having been made by the

Mr. H. A. Mavor.

Corporation Electricity Department, and he quite believed what Mr. Ward had said about being able to get these outside. He thought, however, that a better result would be obtained if the Corporation, who are using such apparatus, instead of applying to cable companies (who are certainly not fitted for carrying out such work), would apply to other electrical manufacturers. With regard to what Mr. Chamen had said about the proposed Omnibus Bill, he (Mr. Mavor) had had his attention called to the clause in question; but he understood that the clause had been modified or deleted. In any case he thought it was a very wise arrangement for the Corporation to hire out motors. The policy of hiring-out had been adopted with great success by the Bradford Corporation.

Mr. Sayers.

Mr. W. B. SAYERS (*communicated*): I regret that I shall be unable to be present at the meeting. There is one point in the paper that I do not understand, namely, the relation between the leakage between sheathing and socket, and Mr. Ward's reference to sheathing which "may be lying in moisture perhaps hundreds of yards away." [See top of page 835.]

Mr. Ward.

Mr. WARD, in reply (*communicated*): The efficiency of ebonite bushes (Fig. 1) for the purpose of insulating bare conductors at the ends of cables has been questioned by Professor Jamieson and Mr. McWhirter. It is well-known that the value of ebonite as an insulator for high voltage is questionable, but I think a good deal depends upon the source from which the material is obtained, the thickness of the material between the parts to be insulated, and the length of the surface over which electrolysis might take place. The thickness of the bushes referred to is ¾ in., and owing to the corrugations, the surface length is 5½ in. I have always made a point to obtain these bushes from Messrs. Siemens Brothers, and have used them considerably for the past eight or nine years for pressures varying between 100 to 500 volts, without, as far as I can remember, a single instance of breakdown.

With regard to the electrolysis of metal sheathings of cables, Mr. Chambers seems to be in the happy position of having never experienced it, and in this, I think, he is to be heartily congratulated. Mr. Chambers submits, however, that proper precautions must be taken, which consist of the continuous bonding of the lead-sheathing across boxes, etc., so as to make it electrically continuous throughout its whole length, and its efficient earthing at a point or points, etc. In the first place, the precaution necessary is one of my chief objections to the system, bonding and earthing adding to the expense while incurring the risk that such may not be efficiently carried out. Moreover, I may mention that, unlike Mr. Chambers, I happen to be one of those unfortunate individuals who have experienced the troubles arising from the electrolysis of metal sheathings. I do not say that they arose, where what Mr. Chambers calls "proper precautions" had been taken, as unfortunately I had to maintain a system of mains in the days (about five years ago) in which we had not realised what the "proper precautions" were. It is evident that Mr. Chambers' experiences could not have dated back to those unhappy times, and that, having benefited by the experience of others, he is now taking the "proper precautions"

Mr. Ward. with a highly satisfactory result. I quite agree with his recommendations and therefore cannot agree with Mr. Burnet's remarks on the subject, in which he suggests isolating the lengths of lead-sheathing. At the same time I have known for some time that there are other central station engineers who have similar views. Mr. Burnet suggests obtaining an opposing E.M.F. between lengths of sheathing by isolating the sheathings on either side of cast-iron joint-boxes. This is certainly a very ingenious idea for preventing stray currents travelling along the lead, but stray currents from outside sources are, unfortunately, not the only troubles to be contended with. I think it is quite as important, if not more so, to guard against electrolysis caused by defects on the mains themselves, with special reference to single conductors. Take such a case as is referred to in Fig. 4, where it may be assumed that a positive leak has occurred on "A" feeder, and a negative leak on "B" feeder, and as suggested by Mr. Burnet, the leads of the two cables are in isolated sections. There might be considerable difference of potential between the end of the faulty section "A" and the faulty section "B," and a current might flow directly through "earth" between the faults without being checked by an opposing E.M.F. set up across the joints; an opposing E.M.F., in fact, making matters theoretically far worse than the insulation resistance between the leads on either side of the joint. Connecting the lead-sheathings of the cables across the joints and also at the central station would assist to convey the current between the leaks along the lead-sheathings of the cables, thus tending to break down the fault and prevent the current passing by innumerable ways through the earth between them, and on to the leads of the faulty sections perhaps at points considerably distant from the actual fault, thereby sowing the seeds for the reaping of further trouble. In the event of a bond in a car-rail becoming disconnected and the metal sheathings of the cables being electrically continuous throughout and well connected to earth at intervals by means of earth-plates, I do not think there would be any fear of damage to the sheathings of the cables if they form temporarily a return path to the station for current which should have flowed through the bond, the section of lead under all ordinary circumstances, I should imagine, being sufficient for the purpose, bearing in mind that only a portion of the current would necessarily be shunted through the lead-sheathing, the rest finding its way back through earth. Mr. Burnet evidently favours the protecting of his cables at the expense of the water and gas mains, but I presume he has not expressed these views to the local gas and water authorities. It would have been of great interest in the discussion on this paper to have heard the views of other engineers who approve of the method of isolating the sheathings, but I think the majority of opinions favour the views expressed in the paper on that subject.

I do not quite follow all Mr. Chambers' remarks on earth-plates. He mentions that in earthing lead-sheathings the currents to be dealt with are either exceedingly small or are only on for a short time. The short time, however, is quite sufficient in which to do the damage. It is not the length of time so much as the difference of potential between the earth-plate nearest the fault and the central station permanent earth, or

perhaps another fault at a distant part of the city which causes the trouble. Arcs in the lead may be produced instantaneously, and that is the very trouble which it is most difficult to guard against. If some time elapsed between the time at which the fault occurred and the fusing or arcing of the lead, the fault might be traced before having caused serious damage, but, unfortunately, especially with the higher voltages in use to-day, considerable damage to the sheathings may occur in a moment, owing to the inefficiency of the earth-plates. I, moreover, do not see that surrounding a plate with coke can be of much advantage unless it is intended, being porous, to retain a certain amount of moisture. Any amount of coke put down in soil which has a low electrical conductivity can but aid the plate in a small degree. I am sorry I have no data to give Mr. McWhirter regarding the electrical resistance between some of the Glasgow earth-plates and earth. I might be able to furnish some if Mr. McWhirter would kindly state what he means by "earth." If he would also let me know whether I should connect one lead of my testing-set on to the earth-plate and the other on to a kerbstone, paving-stone, rock, in a pool of water, or in a slate quarry, I might be able to carry out a few experiments for his benefit. Mr. Ward.

Mr. Scott questioned if the system of fusing as illustrated on Diagram 5 could be efficiently carried out on the whole of the network. Although in my paper I called attention to the fusing arrangement between feeders "A," "B," "C" and "D," it will be noticed that the same method is adopted on the distribution to the left of these feeders, and, in fact, throughout the whole system. I did not go into this important question as fully as I could have wished in the paper, owing to the limit of time allowed for it. I believe in some cases it is the practice not only to fuse all distributors at the feeding points, but also to put in a fuse between the feeder and the distributor 'bus-bar. This is not done in Glasgow, the feeder being connected by a solid copper link to the 'bus-bar. The reason for this is that in any case the feeder must have not only a safe margin over the normal load on the 'bus-bar, but also over any extra load which may be thrown on the bar when a distributor fuse blows in feeding into a faulty section. Under these circumstances, in the event of a fault on the feeder, it is a very remote chance that the fuse between the feeder and the 'bus-bar will blow, especially as perhaps not half of the distributors attached through fuses to the bar are connected through to any other feeding point, and therefore cannot help supplying current for the blowing of the fuse of the faulty feeder. If a fault should occur on any of our feeders we rely upon the station fuses blowing, and also those on any of the distributors connecting the faulty feeder with a good one. Mr. Chambers' method of fusing has already been tried by me, and I have not found it quite as satisfactory as could be wished, for the reason that, although the light fuses between the feeding points may be of considerably smaller section than those at the feeding points, they have nothing but small out-of-balance currents to pass, while those at the feeding points carry all the current going out to the distributor in question. For example, suppose the fuses between the feeding points are

Mr. Ward. put in to carry 50 amperes and under normal conditions for equalising purposes are passing 10 amperes apiece, the fuses at the feeding points are put in to carry 300 amperes, and are passing 200 amperes. It stands to reason that in the event of a fault on a feeder or distributor directly connected with it, the light fuse between the fault and another feeder connected to it by a through distributor, will not blow as intended, but the fuse at the 'bus-bars of this feeder will go, owing to the load on that fuse being proportionately greater than the load on the light fuse between the feeding points. If the out-of-balance between feeders could be accurately gauged, then of course the small fuse between them could be of the required section; but, unfortunately, in the supply to a large city or town, it is hardly possible to keep continually watching these things to a nicety, and, moreover, at different times of the day the conditions of load vary very considerably and throw out the calculations.

Although Diagram 5 shows what has been done in Glasgow, it may be mentioned that the system of mains had only this winter been in anything like a proper working condition, and therefore I do not feel at all confident that what has been done is the right thing, although I look upon it as a step in the proper direction. Glasgow should from now be in a position to furnish some of the most interesting information on the subject, as the system adopted lends itself to any form of arrangement, and owing to the nature of the disconnecting boxes, the circumstances of distribution in any portion of the city can be entirely altered practically at a moment's notice.

Mr. Newington expresses a doubt as to whether it should be necessary to fuse at feeding points, but I think he has in his mind a system of single conductors with an insulating outer sheathing, each conductor being laid in a separate channel of some insulating material. Of all systems of mains I think the above-mentioned is least likely to require fusing for the reason that it is very exceptional for heavy leaks to be possible, and faults may quite well burn themselves clear. But in dealing with a concentric system, especially if lead-covered, on the occurrence of a fault, arcing is set up between all conductors, and will, if the supply is continued to the main, burn it back to the nearest joint-box. These remarks apply equally well to other systems, such as single lead-covered steel-armoured cables, or cables laid on the solid system (where the conductors are not laid sufficiently far apart from one another). I had a very interesting experience about two years ago in which a fault occurred on a triple concentric feeder, consisting of 1 sq. in. + 1 sq. in. + ·3 sq. in. (·3 sq. in. being the section of the outer conductor and the neutral of a three-wire system). Fuses were inserted at the home end of this feeder on the outers only, capable of blowing at a load of 1,200 amperes; the working capacity of the feeder being 750 amperes. When the fault occurred the positive fuse at the home end blew, but not the negative, and nearly twenty yards of the feeder was absolutely reduced to dust, molten copper, and lead, owing to the resistance of the fault between the negative and neutral conductors being too high to allow of sufficient current passing through the fault to blow the negative fuse at the station. Mr. Newington suggests,

instead of fusing the feeding points, that the feeder nearest to a faulty distributor should be switched off. This is one way out of the difficulty, but necessarily entails the cutting out of the whole district supplied by that feeder, which, in my opinion, is not desirable, and in any case is a serious inconvenience to consumers connected to a distributor other than the faulty one. I do not quite follow Mr. Newington's argument referring to Diagram 5. The object of the disconnections shown on the diagram is to save as much as possible, when a fault occurs, the cutting out of good sections of main which are connected between different feeders for the purpose of equalising pressures. In a ringed network, fusing at all points of intersection is usually looked upon as being likely to cause endless trouble, but experience has shown that this idea may be wrong. Suppose a chessboard pattern of network is planned, and two feeders inserted on opposite sides to one another, not in the corners but in the middle of the sides. If a fault is supposed to have occurred in a section of distributor in the middle of the square it will be noticed that no less than six separate distributors feed into that fault, and this means that six sets of fuses are supplying the current to the two fuses on the faulty section, or a ratio of three to one. It seems only reasonable to expect that the fuses on the faulty distributor will be the first to blow, and in fact this has been found the case in Glasgow where certain portions of the system have been connected in this method. If such an arrangement, when universally adopted, would work systematically, the minimum amount of disturbance would be caused on the occurrence of a fault, and the system being a ringed one would be working under the most economical conditions. My remarks on this important subject are made more by way of argument on different methods, than expressing a definite opinion, as I do not profess to have as yet had sufficient experience on the matter. Mr. Ward.

With reference to disconnecting boxes, Mr. Henderson is surprised to learn that four 4-way disconnecting points are used at the intersection of streets in Glasgow instead of one 8-way box. There are several reasons for this. In the first place, in the centre of the city where the density of supply is greatest, cables have been laid on both sides of the streets, and on the 100- and 200-volt supply in the early days, owing to the use of draw-in-systems, boxes at each corner were an absolute necessity. Sections of the streets have been dealt with individually in changing the pressure of the supply to 250 and 500 volts, and consequently new boxes have been required to replace the old ones. Secondly, in adopting a 4-way box as a standard, it is found to be of considerable advantage for use in the outlying districts where, owing to two cables intersecting, a 4-way disconnecting point is required, and the putting in of a 6- or 8-way box would be too great an expense, the outlying districts of a city taking so much longer to develop than the centre. At feeding points, however, an 8- or a 10-way box is put down at one corner of the street and supplies all streets intersecting at this point. This box, however, is 6 ft. square internally, and takes the form of a chamber rather than an ordinary manhole. Should it be necessary to put a feeder chamber in at a certain point where streets intersect, the four 4-way cast-

Mr. Ward. iron disconnecting boxes may be removed in a complete condition and returned to the stores without dismantling anything. They will then be ready for inserting in some outlying district where a 4-way box is required, and all that will be necessary to be done will be to make straight through joints outside the manhole between the distributor ends and the ends attached to the box; thus no waste need be necessary, and the boxes can be used over and over again if the circumstances of distribution require altering.

Mr. Scott and others have asked some information as to the cost of a disconnecting box such as is shown in Fig. 6. Although I do not know what would be a fair price for a manufacturer to ask for such an article, I can give the time and material cost entailed to us in manufacturing them.

	£	s.	d.
Cast-iron box complete, with all cast-iron fittings ...	£8	10	0
Fuse gear, including all gun-metal fittings and ends for four ·25 triple concentric cables...	6	0	0
Manhole cover (uncaulked, but watertight)	2	0	0
TOTAL, COMPLETE	£16	10	0

It may be of interest also to mention that in comparing the price of a brick pit with cast-iron, I make the following comparisons: The cast-iron manhole, as illustrated, provides the cable-end connection boxes and earth-plate, at a total cost of £8 10s. In building brick pits with a view to making them gas and water proof, a lining of pitch has to be inserted between the inner and outer tiers of bricks constituting the 9-in. walls of the box, but even with this precaution we have found both gas and water in the boxes. The cost of such a pit works out at £8, including earth-plates, bonds, and four end connection boxes, thus showing that there is practically no saving in the use of brick, in fact a loss, because the constructing of the pits while the jointer is at work hinders the jointer, and I find that cast-iron boxes can in consequence be put in in half the time. The fact that they are both gas and water tight adds considerably to their value from a maintenance point of view. It may be of interest to mention that in making some notes from our Manhole Inspectors' Reports, I find that with brick pits on the draw-in-system the average daily report gives a return of 25 per cent. with either gas or water or both found in those inspected in a day; while with the same class of pit in connection with the solid system the percentage is 4. Where cast-iron chambers are used, gas or water is, of course, never reported. The high percentage in connection with manholes on the draw-in-system should be regarded as a point worth considering in comparing it with the solid system. The use of cast-iron manholes I do not think would reduce it much, as, although they would save that amount of leakage which nearly always takes place through the brick manholes themselves, most of the water and gas on a draw-in-system drains in from the ducts leading into the manholes. Before leaving the subject of manholes, I might also draw attention to the fact that with the solid system only as many manholes as are absolutely necessary for fusing or disconnecting purposes need

be inserted, whereas on the draw-in-system they have to be inserted at very frequent intervals and sometimes at considerable inconvenience. I might also point out that the difficulty in ensuring that lead-sheathings do not come into contact with cement in brick pits is another objection to this class of box, as it is well known how soon lead deteriorates under such circumstances. Mr. Ward.

Mr. Chambers suggests that instead of an underground box, section pillars should be used. I quite agree that it would be the safest and least expensive method in the end. I do not know what the Glasgow streets would look like with a section pillar belonging to the Electricity Department at each corner, when we already have tramway and telephone pillars as well as arc-lamp and tramway poles crammed into most of the more important street corners. I notice, however, that a certain undertaking in Scotland is erecting section pillars nearly large enough for a mains superintendent to live in. This is, I believe, because on recently endeavouring to localise a fault, it took nearly two hours to make the necessary disconnections in an underground disconnecting box, the box being similar to one I have described in the paper as of the objectionable pattern at present being supplied by manufacturers as a proper standard. I have always had an idea that wherever possible section pillars of a suitable design should be let into the main walls of buildings at street corners, in a similar manner to that adopted in many instances by the Post Office for district letter-boxes. This would give all the advantages which section pillars undoubtedly have over underground chambers without the inconvenience of obstruction usually caused when they are erected at street corners. There would no doubt be the difficulties of way-leaves to overcome, but the experiment is well worth a trial.

I must thank Mr. Henderson for calling attention to the fact that I had omitted to mention three-core cables in my classification. I certainly had overlooked this class of cable. I think, however, it claims to have the same weak points as exist with single conductor systems, a leak from one of the outers or conductors at different potentials from earth being possible without necessarily disturbing the other conductors. This is often the cause of serious electrolysis troubles. I do not see how it can be any cheaper in jointing than a triple concentric cable, although it should be cheaper than three single conductors. The cost of a T-box as used in Glasgow for taking a concentric ·06 conductor off a ·15 triple concentric cable is 11s. 6d., apart from compound. I have priced a box in which a taping has to be taken off the centre conductor so that the two outers must be cut. This of course means that the type of joint referred to is one of the most expensive. The cost of two single T-boxes for a two-wire branch on the same sizes of cables is 14s. 6d., and two boxes take up far more space than one. I do not know what Mr. Henderson pays for his three-core joint boxes, but as three-core cables have the disadvantage that in separating the cables for jointing purposes they have to be spread out to a certain extent, I should imagine the box would be large and take a considerable quantity of compound. It has also been stated that in a triple cable being fed from one end only and with a demand on

Mr. Ward. the far end, in the event of a joint being required to be made the supply to the demand would have to be temporarily discontinued. This is not the case in Glasgow, and we have had, when occasion required it, to complete the joint without interrupting the supply. This is quite easily accomplished with one or two special accessories and ordinary care. In fact there is no class of triple jointing, as far as I am aware, that we have not been able to accomplish with the current on.

In reply to Mr. Newington's inquiry as to the drawing away of conductors from clamps owing to expansion and contraction of the copper, I have certainly come across many cases in which this has occurred, and in consequence never use clamp electrical connections on the Glasgow triples, and where used at all on single conductors, they are always soldered as an extra precaution.

Mr. Newington objects to a statement which he asserts I have made to the effect that a draw-in system ceased to be such on account of branches. I think I stated that it ceased to be of *much value for distributors* owing to the number of branches which become connected with it. Branches to consumers' premises every twenty or thirty feet I certainly think take considerably away from the value of such a system. There is very little left to draw when a fault occurs. It becomes necessary to open the ground at the junction-boxes nearest to the fault, and for the sake of the possibility of drawing the short faulty length we have all the attendant risk in a draw-in system, water, gas, etc. Central station engineers seem to take the report that a manhole cover has blown up as a matter of routine. I must confess myself to having done so when endeavouring to supervise certain systems of mains. I do not know, however, whether the general public look on the matter in quite the same light, especially if they happen to be on the top of the cover at the time. I have seen so much trouble owing to gas, that I certainly think that any system in which gas may be permitted to accumulate under whole lengths of streets is an undesirable one, especially bearing in mind that on a draw-in system the gas is not of necessity collecting from the sub-soil, but may be produced by the heating of rubber, bitumen, or other highly inflammable material used for the insulation of the cables. In Edinburgh, I believe, a system of ventilation is in use in some cases in which ventilating pipes are conveyed from the manholes up the sides of the houses. The cost of all this I do not suppose was reckoned in the capital cost of the draw-in system. Mr. Newington entirely argues from my point of view on the point of a fault occurring and fusing a conductor on to an iron pipe. If he is going to open up the street and cut out a length of pipe at the faulty place, where does the advantage of the draw-in system come in?

I am very much interested in Mr. Newington's useful remarks on copper strip, which I think tend to lead us to the conclusion that it is not the best of systems to adopt. I have certainly seen the effect of the extraordinary force exerted when strips of opposite polarity and in close proximity to one another became short-circuited on both strained and unstrained systems, and I think the information Mr. Newington

Mr. Ward.

has furnished as the results of his experiments is of very much interest and well worth noting by designers of copper-strip systems.

Mr. Chamen mentions the deterioration of lead-covered cables in cement, owing to leakage of current from the ends of the conductors on to the lead-sheathings. I think, however, it is quite possible that a chemical action will take place under any circumstances provided the cement is moist, for the reason that the moisture would be alkaline owing to the lime in the cement, and therefore a solvent of lead. With continuous-current conductors, owing to electric osmosis, a good deal more alkaline solution would be drawn towards the sheathing negatively electrical to earth, and it is probably for this reason it is noticeable that the sheathings on the negative conductors deteriorate more quickly than the sheathings on positive conductors when buried in cement, and where the ends of the conductors have not been efficiently insulated.

Mr. Chamen called attention to Mr. Scott's remarks on wiped joints. Perhaps my reference to this subject was not quite clear. I illustrated in Fig. 2 a joint-box in which wiped joints were used, stating I considered the use of such joints as being one of the easiest and simplest of methods in which to render the lead-sheathings of cables metallically continuous throughout, as well as watertight if wiped properly. Unfortunately my experience has shown that wiped joints are not to be depended upon for being watertight, but I think it would be difficult to find a better method for ensuring metallic connection at joints.

Mr. Field has shown a very good sample of wiped joint as used for all the jointing of the cables on the Glasgow Tramways system, but in this system I believe I am right in stating that all such joints are surrounded by air space in manholes and are not buried in the earth. I think this makes all the difference in considering moisture troubles, and I hope Mr. Field will find it so.

Mr. Sayers calls attention to my remarks on the leakage "between sheathing and socket, and the deterioration of the sheathing at a point perhaps a hundred yards away." What I was endeavouring to explain was that a small current may pass between the socket and the sheathing over faulty insulation, and that the sheathing, while of course deteriorating at this point, would also quickly deteriorate at the point or points at which the bulk of the current would find a path to earth. This point might be at a considerable distance from the point at which the current passed from socket to sheathing, according to the electrical conductivity of the soil in which the sheathing was laid. In such a case, on opening up the ground at the point of the fault, perhaps a hundred yards or more away from the socket, nothing would be seen to indicate that the faulty insulation between the socket and the sheathing had caused the trouble; and this is my reason for advising that not only the soil or ducts enclosing the cable at the point of the fault should be examined, but also the neighbouring joints.

Mr. Munro brings up the question of relative costs of systems, and suggests that they should be tabulated in this paper. Professor Jamieson has also suggested tabulation, and while quite agreeing that

Mr. Ward. it would have been of much advantage to have included such, after deliberating the matter very carefully I came to the conclusion that owing to the elaboration required in dealing with the subject in anything like an adequate manner, it would be best for the purposes of the paper to omit it. One of the chief difficulties is the want of standardisation, engineers' views differing so widely in their ideas of the requirements for different systems. For these reasons and also the fact that I have personally never been fortunate enough to have the management of anything but a mixed system, I do not feel myself in a position to give any data which would be of much value on the subject.

Regarding Mr. Munro's remarks on the use of pitch instead of bitumen as a filling-in for cables laid on the solid system, over three years ago I took this matter up very carefully, feeling convinced that the best coal-tar pitch, mixed with a certain amount of shale oil for softening purposes, would be quite as suitable a material for the solid system as unrefined bitumen, while being about one-fourth the price. I had at that time the tests and experience of some of the best analytical chemists in the country, all of which bore out my views on the matter. Notwithstanding the fact that some engineers prophesied destruction of the lead-sheathings in a short time (although not being able to quote any instances of actual practical experience on the matter), since that time (three years ago) in Glasgow we have used coal-tar pitch, but of the very best quality, and I have not yet seen the slightest sign of deterioration of the sheathing on any of our lead-covered cables which could be attributed to the use of pitch. I will say, however, that Trinidad bitumen is far more adhesive to the lead, and in this respect is better than pitch; at the same time I do not think this warrants the extra expense incurred in using it. My remarks on the comparison of pitch and bitumen also apply to cables with sheathings other than lead. I have not noticed appreciable local electrolytic action between lead, iron, and brass in cable jointing, since making a practice to ensure thorough metallic contact between the metals.

Regarding my reference to what are called "pin-holes" in lead-sheathings, they have no reference to holes found in the cable after laying it. I have on several occasions been fortunate enough to detect pin-holes in the sheathings before the cable has been put under the ground, and have therefore been in the satisfactory position to explode the manufacturers' theory that nowadays it is impossible for such things to occur in manufacture. There may be several cases in which these defects have caused breakdowns that I have been unable to account for satisfactorily, as the fault nearly always destroys all trace of the original cause, and naturally the manufacturers' explanation under such circumstances is that some person unknown has put a pick through the sheathing. I have never made a trial of the system of mains Mr. Munro suggests, that is to say, two concentric mains laid solid, with the outers forming the earthed neutral of a three-wire system. Presumably Mr. Munro's object is to avoid disturbance to all three conductors in the event of a short. This certainly is one of the

Mr Ward.

chief objections to a triple concentric main, but the two concentrics have the disadvantage over either triple or three single conductors, in that the neutral wire would not be common to both sides of the system, except where specially made so at junction-boxes. Consequently the neutral would require to be of the same section as the outer conductors of the three-wire system. This, together with the extra thickness of insulation and sheathing required for mechanical strength where two separate cables were used, would, I think, so add to the cost as to make any advantage claimed for the system of little value.

Mr. Mavor suggested pouring molten lead into the pocket of a joint-box and around the lead-sheathing of the cable brought into the box. I had this in view some years ago, but never put it into practice for the following reasons: (1) The lead poured in would contract, and therefore if metallically adhering to the sheathing of the cable would not do so to the cast-iron joint-box, and consequently the joint would not be watertight, neither would a good bond be effected; (2) The body of lead poured in would concentrate so much heat round the sheathing of the cable that it would be quite possible for the sheathing to become partially destroyed, and a very little want of careful observation on the part of the jointer might leave this undiscovered. Mr. Mavor evidently favours earthing the neutral on a three-wire system throughout, but although central station engineers might wish from one point of view to do it, apart from the difficulty of doing it efficiently there is the inconvenience it would cause in fault localising. In Glasgow, by means of certain tests carried out from one central station, it is possible to locate leaks and faulty insulation in different parts of the city to within a certain small area. Such an arrangement is of considerable value and saves local disconnection and testing, which in a large system is a very laborious task. If the neutral wire, however, is earthed throughout, these tests cannot be effected. The only manner, in my opinion, in which to accomplish Mr. Mavor's "earthing throughout" would be to use an uninsulated neutral forming the outer of a concentric system, sheathed, if considered desirable, with a lead-sheathing. I believe there is a system at work in the south of England on this principle, but I do not know whether it has met with any measure of misfortune.

I am pleased to receive Mr. Mavor's support on the subject of the manufacture of jointing appliances, as both Mr. Chambers and Mr. McWhirter seemed to have considered my remarks unduly severe on manufacturers. Mr. Chambers blames consulting engineers, and this is the first time I have heard it expressed that consulting engineers should design joint-boxes. Does Mr. Chambers also approve of consulting engineers getting out their own specifications for the manufacture of cables? I was under the impression that one of the objects of the promotion of the Cablemakers' Union was to avoid this sort of thing as much as possible. I quite realise the difficulty that contractors experience in trying to meet the requirements and ideas of everybody and to cut the prices, but this should not deter them from devoting a little attention to some good designs, and keeping them in stock to meet the requirements of those engineers who know by

Mr. Ward. experience the value of a good article and are ready to use it. In endeavouring to get out such designs, I would suggest that a practical jointer or foreman be kept in continual attendance in the drawing-office, and be allowed to express his opinion on any points in the design in which he may imagine there is a weakness, as it stands to reason that the best of draughtsmen may not be aware of all the little difficulties to be met with in working their designs in under the streets. It is the jointer or mains foreman who understands most about such matters, and I am firmly convinced it would pay to enlist his services before launching, perhaps at considerable expense, what might prove to be an unsuitable design on the market as a new standard.

Mr. Sam Mavor has asked if there are any of the old rubber mains, as used on the 100- and 200-volt systems, still in existence in Glasgow. There are several sections still working, not only on the old system, but also at 250 and 500 volts. Some sections have very soon broken down when changed over, others have never done so, and appear to be quite good, but my experience has been that it is not at all advisable to rely upon such cables. Regarding triple concentric distributors, I believe it has been mentioned that single conductors give more notice of defective insulation before actually breaking down. I do not altogether agree with this, as for the past two months weekly fault-localising tests have been taken on the Glasgow mains, with the result that we have been able to remove as many as eight faults on the outers of concentric mains, without the mains breaking down, and in some instances I know that the defects had been in existence for at least four weeks before being removed. Most of the faults were pick-holes, or cases in which a hole had been arced in the lead owing to insufficient bonding or earthing. Moreover, I am of the opinion that the life of defective concentrics could be prolonged by arranging the conductors so that the earthed neutral of the three-wire system would be the outer conductor of the cable, the positive the middle conductor, and the negative the core. In this manner suppose a defect occurred in the sheathing which let moisture into the neutral conductor. There would not be the tendency due to electric osmosis for the moisture to be drawn through the insulation between the neutral and the middle or positive conductor. In fact, the effect would be exactly opposite, and would tend to prolong the life of the insulation under circumstances of defective sheathing. This is a point that might be worthy of consideration in laying out a new system of concentric mains on the three-wire system. It also, I think, gives concentrics a standard of safety higher than that obtainable with three single conductors, where the negative, so to speak, is not electrically protected from moisture by the positive conductor.

In conclusion, I wish to express my thanks to all those gentlemen who have so ably contributed to the discussion, and through their remarks made the discussion of so much more interest and value than the actual paper. I also would like to take this opportunity to thank the staff of the Drawing Office and also the Workshop of the Electricity Department, for their valuable assistance in supplying the drawings and models referred to.

BIRMINGHAM LOCAL SECTION.

SURFACE-CONTACT SYSTEMS OF ELECTRIC TRACTION.

By W. Kingsland, Member.

(*Abstract of Paper read January 22, 1902.*)

After giving a description of the various surface-contact systems of electric traction, pointing out their advantages and drawbacks, there were, he said, four methods of applying electricity for the propulsion of vehicles: the storage battery, the trolley, the open conduit, and the surface-contact systems. The latter was still looked upon as more or less of an experiment, but it was steadily, if slowly, coming to the front, and there were many who, like himself, predicted a very great future for it. The trolley system, which, principally from commercial considerations, was an easy first at the present time, was not wanted in our towns, as it was certainly a source of danger and was by no means a desirable addition to the equipment of our streets. Mr. Kingsland went on to trace the developments which the surface-contact system had undergone in practical working, and by the aid of diagrams and photographs thrown on a screen he pointed out the essential characteristics first of the group of double-stud systems equipped with magnet in switch, then the single-stud system with the magnetised and non-magnetised skate; and finally the mechanical systems of Anderson and himself, the former depending on the double stud and his own on the single stud. He claimed that the mechanical systems had an immense advantage over the others, all complications of magnets and coils being obviated. The details of the switches employed in the mechanical systems were explained. Mr. Kingsland said that the particular feature of his own system was that the switches were operated by means of an arrangement fixed to the car. The car had two strikers dependent from it, one at the front and one at the back, and those strikers went down into a slot which was formed by setting up a rail outside the ordinary track rail, and operated tappet wheels. There was no switch apparatus whatever within the stud. Of course the slot itself might be a groove in the rail, but that would necessitate the alteration of the ordinary track construction. The connection between the main and the studs was exceedingly simple. Mr. Kingsland exhibited specimens of the switch, the tappet wheel, the inner switch-box, and the commutator, pointing out the means by which mechanical difficulties had been surmounted. Having explained the working of the "star-wheel" switch which he had originally invented, he said he had always had in view a switch in which instead of employing a star-wheel to move round and round, one lever arm only should be employed, which could be pressed down by the striker and returned automatically so as to be

ready for the next stroke. He had now perfected this switch, and its operation could be seen from a sample one which he had on the table in front of him.

Mr. Bornand.

M. VICTOR BORNAND, who had superintended the laying of one of the lines on the Claret-Vuilleumier system, said that there were two systems used in Paris, viz., the Diatto and Vedovelli system, where each switch was below its respective stud; and the Claret-Vuilleumier, where one switch operated a number of studs. In the former systems, to work successfully, each stud must be carefully insulated, for even if the switch works properly the dust and mud has an appreciable conductivity, and there is always a certain amount of leakage between the rail and the stud which, at a pressure of 600 volts, gives rise to sparking after the car has passed over the stud. If vulcanite, indiarubber, or bitumen enter into the composition of the insulating material this sparking produces decomposition, and the gases given off inside the air- and water-tight switch-box may generate a dangerous pressure, and an explosion due to such causes has occurred on the Diatto system, where vulcabeston is the insulating material used. In the Claret-Vuilleumier system this difficulty is overcome by using one switch for a large number of studs, and the switch can be placed under the pavement or road according to convenience. Also the insulation used is mica, and accumulation of moisture or gases is prevented by ample ventilation. This system is now working very successfully, and has been definitely adopted in Paris and approved by the Service du Control, which corresponded to the English Board of Trade.

Mr. Jones.

Mr. JONES asked what happened in the event of the skate coming in contact when alive with a piece of iron or any other conductor. It seemed to him it might result in a heavy short. He had seen the piece of line put down at Wolverhampton on Mr. Kingsland's system, and was struck with the apparent value of the system. It certainly seemed to him at the time that Mr. Kingsland was presenting to the public a solution of the problem which had been before the engineering world for some time, as evinced by the number of stud systems introduced.

Mr. Vaudrey.

Mr. J. C. VAUDREY said there were two points about the Claret-Vuilleumier system in Paris which struck him as particularly objectionable. In the first instance the studs (which represented practically the studs which Mr. Kingsland proposed for his own system), to be a success, must be half an inch above the level of the street, and should always be maintained at one dead level. They must therefore be made of some hard material. It had become a recognised fact that on tramway tracks they must have wood pavement, and, as far as he had seen, it was impossible to maintain even wear and tear between the stud and the wood pavement. In Paris each of the studs was surrounded by a little hollow, six or eight inches in diameter, which in wet weather was full of water. He could not think those "puddles" would ultimately be allowed in our cities. Assuming that the insulation of such blocks could be maintained, which he very much doubted, the other objection was almost as fatal. In the Claret-Vuilleumier system the concentra-

tion of the feeder wires in a large cast-iron box about a couple of feet in diameter in the street, filled with a series of coils and magnets, seemed a most complicated system of working, and how it could last for a long period he could not see, as moisture must be fatal to the system. Apart from the studs in the road, he thought Mr. Kingsland would find great difficulty in maintaining the switch contacts. Mr. Kingsland's switch consisted of three metallic faces with an insulating medium between. His experience was that switches working on 500 volts with any sort of medium would sooner or later spark. Mr. Kingsland hoped he would be able to maintain a perfectly dry box; he (Mr. Vaudrey) only hoped his expectations would be fulfilled. His experience was that when the greatest possible care was taken street boxes, which were apparently absolutely tight, sweated, for no other apparent reason except perhaps the porosity of cast iron. Mr. Vaudrey.

Mr. A. M. Taylor recalled cases of electrocution which had occurred in connection with one of the Paris systems, and said the weak point of these surface-contact systems was that, although the inventors all claimed that the surface plate was only alive when the car was over it, and although some of them professed to have means of making it dead, the common fault with all of them was the danger of the plates being left sufficiently alive to do terrible damage and destruction in the street, even though all the apparatus was working properly, through the possibility of moisture getting into the switch-boxes. That either this happens, or else that the automatic apparatus does sometimes fail, is proved by the numerous cases in which horses have been killed on the Paris lines by contact with the studs. In all these systems in which they had a large number of switches buried in the roadway and inaccessible, there was a very large number of potentialities of danger which they could not very well get rid of. He could not help thinking that those systems which aggregated the switches all together in one box were rather a step in advance, though he quite saw their weak points. He could sympathise with Mr. Kingsland because he had been an inventor in this line himself. He thought Mr. Kingsland had overcome the difficulties of the mechanical system very well indeed, and if any surface-contact system which was dependent on switches buried in the roadway was going to succeed, he thought Mr. Kingsland's would. The systems described had been tried hitherto in countries where there were no Board of Trade regulations. He apprehended that a very substantial leak must occur in very wet weather, when, not only the studs, but probably the skates as well, would be buried in water. He fancied, too, there would be great difficulty in maintaining the contact when snow got driven down on the track. There would be some nasty flashes if a stone got under the skate and tipped it up with 500 volts on. He apprehended that, on a large system, the temptation to the skate to make "shorts" would necessitate a staff of men to replace fuses in the pillar boxes, and the interruptions to regular traffic would be very serious, on a frequent service. Mr. Taylor.

Mr. Samuel Bennet thought the last speaker ignored the fact that each box was thoroughly well drained, and that it was impossible at Mr. Bennet.

Mr. Bennet. any time to get half an inch of water on the stud. [Mr. TAYLOR: I should like to ask the cost of Mr. Kingsland's system of drainage.] I do not think it would exceed £90 a mile.

Mr. Vaudrey. Mr. J. C. VAUDREY pointed out that any system of tramway drainage would be the common system of the town. This often failed when most needed, and for this particular purpose would be unreliable in many towns.

Mr. Lea. Mr. HENRY LEA (*in the Chair*), alluding to a remark by Mr. Kingsland to the effect that trolley-wires were not desirable in our streets, said he agreed with him so far as it related to the centre of a town, but when they got to the more scattered portions of a town, where there was no longer any necessity for that fearful-looking network of overhead wires, then it seemed to him that when once you had spoiled a street by putting in tramlines, you did not spoil it much more if you put the overhead wires in; and the simplicity of the overhead system left nothing to be desired. In contrast with that he could not but be struck with what seemed to be the great complication attaching to nearly all the systems which had been put before them to-night. The idea of having an electric switch underneath a muddy street every fifteen feet, depending for its action upon magnetic influence or springs, suggested that we had not yet arrived at a system which would turn out to be really practical for the rough-and-ready work of our muddy, snowy streets. He should like to ask Mr. Kingsland what would happen to his screw clutch if the springs broke and failed to return it to the position for making the next movement. If the practicability of the scheme depended upon springs he was afraid it rested upon a somewhat insecure foundation. He would like to know what prevented the tail end of the skate being forced by its spring on to the roadway when it left the stud. He could not imagine this multiplication of apparatus underneath the street level always acting; and if the cut-offs failed, leaving the studs alive, there would be sure to be a number of fatal accidents.

Mr. Kingsland. Mr. KINGSLAND, in reply, said what everybody wanted was a system which gave no trouble whatever, and in which nothing was likely to go wrong. He was afraid they would not get those advantages in any system. Of course the trolley system itself had given much trouble, and killed several people. If the trolley system were now coming in as a new thing, he thought very much more might be urged against it than anything he had heard that night as a criticism on the stud system in general. It was true that a large number of horses had been killed in Paris, and he believed they had all been killed by the Diatto system, in which a mercury contact was employed, and a plunger was drawn up in a very small switch-box, there being therefore great liability to heating. The Claret-Vuilleumier system had been working at the Place de la République since 1896, and he thought that was a fairly successful run. He certainly should not put his studs in as those in Paris were put in. His stud was put into a special concrete block, and there were special facilities for taking out the steel portion—the wearing portion—and replacing it in a very few minutes. It was almost impossible for a pool to form round it. A

question had been asked as to what happened when a short occurred on a skate. All that could be done was to blow the fuse in the sectional pillar-box. Mr. Vaudrey seemed to be under the impression that the switch contacts were broken in the switch-box. There was no sparking whatever in the switch-box, providing the switches were operating properly, and one came on before the other went off. The particular switch and commutator he was using had been thoroughly tested. They had repeatedly broken as much as 60 amperes in the switch, at 500 volts, and there had been no damage. The question of moisture was a serious one, of course, but he was not afraid of a small amount of water getting into the switches, which would be regularly inspected and could be replaced in a few minutes. He had never had a breakage in the spring arrangements to which Mr. Lea referred. Moreover, there were six springs, and if one broke five remained to operate the clutch. With regard to the question which had been asked as to the danger of leaving the studs alive, even the best-regulated apparatus failed at times; but there was a positive method of obviating a live stud, viz., to put an earthed trailing brush behind the skate. That was one of the regulations he anticipated that the Board of Trade would insist upon. Mr. Kingsland.

Dr. SUMPNER, in proposing a vote of thanks to Mr. Kingsland, said that the author's system had the great virtue of simplicity, and seemed to him more likely than any other to be a success. Dr. Sumpner.

MANCHESTER LOCAL SECTION.

THE SUPPLY OF ELECTRICITY IN BULK.

By Hardman A. Earle, Member.

(*Paper read January 28th*, 1902.)

Large Power Supply Companies are not of yesterday, for we are acquainted with the large works which are in operation in Canada, America, and on the Continent of Europe.

Some of the better known of these large undertakings are the following :—

Chèvres, Geneva, utilising the power of the Rhône. At this station 14 1,200 horse-power generators are installed, which can give either single or two-phase currents at 45 periods, and at either 2,750 volts or 5,500 volts. A fifteenth machine is of the same power, but of continuous current for electro-chemical purposes. The distance from Chèvres to Geneva is a little over 3½ miles.

Niagara, in America. The operations of this large power station are continually increasing. To the original power house, with a capacity of 50,000 H.P., a second wheel pit is being added which will double the capacity. The 10,000 H.P. sent to Buffalo, nearly 20 miles, is to be increased to some 30,000 H.P., at 22,000 volts, with 3-phase transmission at 25 periods.

The St. Lawrence River Power Company at Massena, in the north of New York State, has completed the erection of the first portion of its large power plant. This undertaking contemplates ultimately using 150,000 H.P., the capacity of the present canal being 75,000 H.P. The plant in the first instance consists of seven 5,000 H.P. generators, each driven by three pairs of turbines. The 3-phase generators run at 150 revolutions per minute, with a periodicity of 25 and a voltage of 2,200.

Paderno, Milan. At this station the power of the River Adda is utilised. Energy is transmitted to Milan, a distance of some 20 miles. The station has a horse-power of 13,000; current is generated by 3-phase machines, at 13,500 volts and 42 periods.

Vizzola, Lombardy, utilising the power of the river Picino. There are ten 3-phase generators each of 2,500 H.P., the voltage being 12,000.

Besides these large undertakings, there are many stations from which power is being transmitted long distances at very high pressures, the following being a few examples of 3-phase work :—

Sacramento Elec. Co., Folsom, California :
3,000 kw., transmitted 22 miles at 11,000 volts, 60 periods.

Pioneer Elec. Power Co., Ogden, Utah :
3,750 kw., transmitted 40 miles, at 26,000 volts, 60 periods.

Telluride Power Transmission Co., Provo, Utah:
1,500 kw., transmitted 55 miles, at 40,000 volts, 60 periods.
Hudson River Power Transmission Co.:
3,750 kw., transmitted 18 miles, at 12,000 volts, 38 periods.
Montana Power Co., Butts City, Montana:
3,000 kw., transmitted 21 miles, at 26,000 volts, 60 periods.
South California Power Co., Redlands, California:
3,000 kw., transmitted 80 miles, at 33,000 volts, 50 periods.

Considering these splendid examples of large power stations, transmitting energy long distances, the English power schemes cannot in any way be classed as speculative ventures; for when so many similar undertakings exist, and so much thought has been given to the matter by engineers in other countries, the information at hand renders it possible, to design and erect our new stations upon the most economical and efficient basis.

It may be contended that these large schemes abroad have unlimited water power at their disposal, and that therefore the results are not comparable with our future power stations. The first cost of large water-power schemes is, however, usually very much higher per horse-power than similar schemes where coal is used, and the distance that the energy has to be transmitted is, moreover, almost invariably very much greater, and large sums must often be paid for concessions to utilise the water.

There is one point in connection with these foreign schemes which will be noticed, viz., that the voltages are much higher than those customary in this country. This is due to the universal use of bare conductors, for which the most economical voltage is much higher than for insulated cables.

The supply of electricity in bulk is, in this country, an undeveloped industry, but it is one which has, during the years 1900 and 1901, been brought most prominently forward by the promotion of a large number of Power Bills, having this object in view. Many of these have received the sanction of Parliament, and it is the object of this paper, in some measure, to consider the powers which have been granted to these Companies, and their importance as regards the distribution of cheap power, and I shall also endeavour to forecast their chances of success as commercial undertakings. With this in view I cannot, in the first instance, do better than give a list of the principal Acts which have received the Royal assent, together with the extent of their areas, their capitals, and the number of generating stations scheduled in the Acts (see p. 886).

These far-reaching schemes have, like all other new developments, been subject to the most rigorous criticism by professional witnesses, by opposing corporations, and by conscientious objectors. The arguments used were practically on all fours with those adopted in opposition to railways and gas, and many statements were made by witnesses, who will, without doubt, have to eat their own words.

In the same manner as it was said of railways that they could never pay interest on the money expended on their permanent way, so was

	Name of Company.	Share Capital.	Borrowing Powers.	Total.	Approximate area in square miles.	No. of Generating Stations.
		£	£	£		
1900	County of Durham	500,000	166,000	666,000	250	
1900	South Wales	750,000	250,000	1,000,000	1,050	3
1900	Lancashire	3,000,000	1,000,000	4,000,000	1,200	4
1900	North Metropolitan	500,000	166,000	566,000	325	2
1901	Derbyshire and Nottinghamshire	1,800,000	600,000	2,400,000	1,570	4
1901	Cleveland & Durh'm	1,000,000	333,333	1,333,333	820	6 or 7
1901	Shannon Water Power	365,000	180,000	545,000	Radius of 30 miles.	1
1901	Clyde Valley	900,000	300,000	1,200,000	732	3
1901	Yorkshire	2,000,000	666,666	2,666,666	1,800	4

it said that the Power Companies never could pay interest on their mains; but notwithstanding, powers have been granted to a large number of companies. The Bills promoted in 1899 were unsuccessful in that year, but upon being re-introduced in 1900, in a form more in accordance with the wishes of Parliament, the first great step forward was made, when the following opinion was expressed by Sir James Kitson's Committee in May, 1900: "That the value of electrical energy as a means for the transmission and application of power has been amply demonstrated, and its importance to the industries of this country is admitted. The Committee accordingly advise that it is of public advantage to facilitate measures which may ensure a general supply of electrical power to all consumers who may seek to avail themselves of the economy and efficiency offered in the service of these sources of application of power."

Taking into consideration what had already been done abroad, one cannot but express surprise at the opposition with which these Bills were met, and at many of the arguments which were used against them; and that it should have been necessary for Sir James Kitson's Committee to have expressed the above opinion, to enable the schemes to proceed at all, is most extraordinary.

The opposition experienced may be divided under two heads: firstly that of Local Authorities, who, having expended large sums of money on their own central stations, did not wish to be exposed

to competition; they at the same time held that they could supply as cheaply as the Power Companies, and they also could not agree to speculators with a roving commission taking up their streets; and secondly the opposition of those who held the schemes to be unnecessary, and likely to prove financial failures. The first objection has been ruled out by Parliament, and the second I will endeavour to discuss. The Local Authorities have been fully protected, for though the Acts are not all quite upon the same lines, the powers of the Companies are practically as follows :—

(1) Energy shall be supplied by the Company.

(*a*) To authorised undertakers, and
(*b*) To persons requiring a supply of power.

(2) The Company shall not supply energy for lighting purposes except to authorised undertakers, provided that the energy supplied to any person for power may be used by such person for lighting any premises or any part of which the power is utilised.

(3) The Company shall not supply energy (unless specially provided for in the Act) in any area which, at the date of the passing of the Act, forms part of the area of supply of any authorised distributors without the consent of those distributors.

There is also a section in the Act with regard to conversion, which reads as follows :—"The prices to be charged by the Company shall not exceed those respectively stated in the schedule, and such prices shall include the cost of transforming the energy supplied (if so required by the authorised undertakers or persons supplied) to such pressure and description of current as such undertakers or person may require.

Wayleaves have been granted through both the larger and the smaller townships, but to minimise as far as possible annoyance from taking up streets, the Companies have, as a rule, been excluded from passing through certain central portions of the towns, the excluded areas being defined by the area of a circle drawn by a mile radius from the Town Hall, or some other similar area mutually agreed upon and sanctioned. The Corporations have, therefore, received ample protection.

It is desirable that the scope of these large companies should be thoroughly understood. Their object is not to retail electricity to small consumers, but to supply in bulk to corporations, and to authorised undertakers, and to large works requiring a supply for power, and which latter are situated outside any present authorised area. They are not, therefore, permitted to compete either directly or indirectly, or to supply in areas which, at the date of the passing of the Acts, formed part of the area of supply of any authorised distributors, without the consent of those distributors.

At first sight, some might assume that these restricted powers leave but little for the new power companies to do. It does not, however, require any very lengthy study of the question to appreciate the

enormous field that is open, and that, notwithstanding the number of electrical works that are already in operation, the demand they are supplying is but a fraction of future developments.

The larger towns are certainly provided with their central stations for light and power, and those who reside within their areas are in a position to obtain current upon reasonable terms.

The number of electricity works in operation in Great Britain and Ireland amounts to some 200. Besides these, some 270 other provisional orders have been granted, but not more than half of these latter have found it desirable to commence the erection of works.

Quite apart from the supply of power, there are therefore large numbers of smaller towns which, although they have obtained an order, find that their cost of production, on a small scale, would be too high to ensure a good return on money spent.

A better illustration cannot be given than the situation in the manufacturing portion of the West Riding of Yorkshire, which area of about 1,800 square miles is now comprised in the scheme of the Yorkshire Electric Power Co. Within this area of supply there are the following local authorities :—

	Number of Authorities.	Works.	Provisional Orders.	Applications.
County Boroughs	5	5	—	—
Non-County Boroughs	13	6	4	2
Urban Districts	118	—	12	4
Rural Districts	21	—	—	—
	157	11	16	6

Of these 157, therefore, only 11 have works established and giving a supply, namely : —

	Units sold.	Load Factor.	Total Costs.
Barnsley	—	—	—
Bradford	3,424,658	14·26	1·22
Brighouse	—	—	—
Dewsbury	232,907	11·31	2·96
Doncaster	—	—	—
Halifax	1,896,667	16·68	1·28
Huddersfield	951,033	10·72	1·53
Leeds	2,520,414	11·28	1·31
Morley	77,776	10·57	4·29
Sheffield	2,381,708	12·08	1·52
Wakefield	229,818	10·75	1·93

(The above figures are taken from the last published returns.)

The inhabitants of the above towns number approximately 1,500,000, and the remaining 1,000,000 inhabitants in the district have to generate their own current or do without.

Five other generating stations have just started in this district or are

about to do so, namely, Batley, Heckmondwike, Keighley, Rotherham and Shipley. An electric supply is, however, available only over 130 square miles out of the 1,800 included in the Yorkshire Co.'s area.

From these particulars it will be seen that even in this one district there are 141 local authorities totally unprovided for. This is not a state of affairs peculiar to this district, for the same story can be told in connection with the districts of all the large power schemes.

It is estimated that in the Yorkshire Power Co.'s area there are some 27,000 factories and workshops, and that these require some 2,000,000, horse power to drive them. This latter figure is but a rough approximation, but clearly shows that the Company may confidently anticipate a good demand for power, to provide a load for the generating stations representing 100,000 I.H.P., which they intend to erect.

I now propose to consider the engineering of these power schemes, which in England and Wales are based upon the problem of transmitting energy from the coal pit centres.

The points for consideration are :—

Board of Trade regulations.
General system.
Cost of generating stations.
Cost of trunk mains.
Cost of sub-stations.
Cost of distributing and service mains.
Total expenditure and capital account.
Works cost per unit generated, including management.
Trunk mains, upkeep and superintendence.
Expenditure at sub-stations and upkeep.
Distributing and service mains, upkeep and superintendence.
Summary of expenditure per annum.
Analysis of total units sold per annum.
Total cost per unit sold.
Rates of charge.
Financial results.

In every problem it is, in the first instance, necessary to put down the known quantities, and in the question before us, there are certain Board of Trade regulations with regard to the voltage which may be employed for transmission, and supply, and the energy which may be transmitted by any one main.

The regulations prescribed by the Board of Trade under section 4 of the Electric Lighting Act, 1888, relate to low-pressure and high-pressure supplies; the latter being a pressure over 500 volts, but not exceeding 3,000 volts. If these regulations could not be departed from, these large schemes could not be economically carried out. Consent has, however, in several instances been given to extra-high pressures being adopted, and at the same time the energy which any single main may carry has been fixed.

The following table gives particulars of nine of these special cases.

Consent given.	Name.	System.	Periods.	Max. Volts on Trunk.	Type of Main.	Max. Carryg. Capacity each Trunk Line.	Max. Power to any dist. station.
28th Feb., 1899	London Electric Supply	Single-phase	83	10,000	Concentric	1,000 k.w.	
7th June, 1899	Wandsworth E.L. order			6,600		600 k.w.	750 k.w.
18th Dec., 1899	Croydon Corporation ...		60	5,500		.	750 k.w.
16th Feb., 1900	Kennington, Notting Hill	3-phase	45	5,250		1,000 k.w.	
19th Feb., 1900	Manchester	3-phase		6,500	3-Core	1,000 k.w.	
13th June, 1901	Dublin	Single-phase	50 60	5,500	Concentric		
31st July, 1901	Metropolitan	2-phase	75 100	11,000		1,000 k.w.	
20th Aug., 1901	Newcastle-upon-Tyne...	3-phase	40	11,000	3-Core		E 1000 k.w.
20th Aug., 1901	Walker Wallsend Union Gas Co.	3-phase	40	11,000		1,000 k.w.	

It is unnecessary, in the schemes actually before us, to apply for permission to generate at a higher pressure than 11,000 volts, which voltage has, as already stated, been sanctioned in several instances by the Board of Trade. It must, however, on the other hand, be considered whether it is necessary to work at so high a pressure.

A lower voltage means more copper in the mains but less expensive insulation, and some reduction in the cost of the generators, transform-

ing apparatus, and possibly switching gear, and as there will be a large number of sub-stations and distributing centres, it is a matter of importance what pressure it is desirable should be introduced into these.

In laying down a number of stations to supply a large area with energy, every endeavour must be used to simplify the plant to the greatest possible extent, and at the same time to ensure its reliability and suitability for the work to be performed. There are, however, two factors, which do not admit of our basing our scheme merely upon the question of simplicity, and these are—first cost, and economy of working.

In considering the general system, we must ascertain as far as we are able the nature of the demand, the uses to which the energy is to be put, the distance from the generating station to which it is to be transmitted, the amount to be converted, and the quality of current and pressure into which it has to be transformed. There is also the periodicity.

25 periods is good for rotaries, but is rather low for high voltage incandescent lamps.

40 periods would appear to give the cheapest installation for all purposes; and

42 periods has been assumed to be the lowest admissible for arc lamps.

A definite decision on this point is necessary, and it is highly desirable that a standard should, if possible, be fixed.

Of the large schemes, the Yorkshire Power Company is the one with which I am best acquainted. It has four power stations scheduled, the three most important of which are situated on the coal fields and surrounded with factories and works of all descriptions, and, with the exception of a small outlying portion of the area, 12 miles is practically the maximum distance to which it will be necessary to transmit energy. The four stations will average 25,000 I.H.P. each, and although some will develop more quickly than others, we can consider how the 100,000 I.H.P. which it is intended shall be installed will be distributed.

I have made a rough approximation, as given below, of the uses to which the power will be put.

	Load Factor.
15 per cent. for Tramways and Light Railways	50 per cent.
60 per cent. „ Motors	... 30 per cent.
25 per cent. „ Lighting to Authorised Undertakers ...	11 per cent.
100 per cent.	

This gives a load factor of 28 per cent; 25 per cent. has, however, been assumed in all calculations.

The above load Factors are not those for individual cases, but the resultant Load Factor at the generating station.

Of the total power generated at each station, I have assumed that 20 per cent. can be sold as generated without conversion; for it has been found, upon canvassing the district, that a very large load can be

obtained within a three mile radius of the principal stations (for which no conversion will be necessary), for a considerable percentage of the output without any expenditure on high tension trunk mains, the more remote portions of the area will have to be subsequently dealt with; but during the first two or three years, while the station is lightly loaded, and the cost of generation per kilowatt is relatively high, the initial expenditure will not overweight the concern.

Taking the cost of the generating stations next into consideration, my calculations are based upon the cost of four generating stations, each of 25,000 I.H.P., equalling, at 84 per cent. efficiency, an output of 15,666 kilowatts; and I have allowed for the following sets:—

4 of 5,000 I.H.P. each	20,000 I.H.P.
5 of 2,000 I.H.P. each	10,000 I.H.P.
9 sets	30,000 I.H.P.

This provides for sufficient plant to take the full load, even if one of the large sets were shut down. At any time desirable, however, some of the load could be transferred to another station.

Cost of each station:—

Land and Buildings	£30,000.
Boiler-house Plant, Condensers, Pumps, Coal Conveyors, etc.	120,000.
Switch Gear, Direct Current Boosters and Cables in Station	30,000.
Engines, Generators, and Exciters	150,000.
(Including spare plant as given above.)	
	£330,000
	4 stations.
	£1,320,000

The cost of trunk mains to transmit energy from the generating stations to the sub-station converting centres, constitutes a large and important item in the total expenditure.

The Board of Trade has fixed a standard of thickness for the insulating material with which a cable shall be covered. The minimum thickness may not be less than one-tenth of an inch, and in cases where the extreme difference of potential exceeds 2,000 volts, the thickness of insulating material shall not be less in inches, or parts of an inch, than the number obtained by dividing the number expressing the volts by 20,000. The point has been frequently raised that the thickness specified is excessive; but for the purposes of this paper, cables are taken conforming to the regulation, and which can at the same time be used with the centre unearthed.

It will be interesting briefly to consider the question of earthing the centre-point of the star in 3-phase working. The argument for earthing is more easily appreciated than the opposite.

In a 3-phase system with, say, 10,000 volts between any two of the

three wires, each of these wires is at 5,775 volts difference of potential from the centre point. If this point is earthed, although the insulation between any two wires must withstand 10,000 volts, that between any conductor and earth may be reduced to withstand 5,775. If no point of the system is earthed, and the insulation resistances of all three wires is equal (irrespective of their respective values), then each conductor has but 5,000 volts to earth; but if the insulation resistance of the three wires differs (as it always will), then the potential difference to ground of the circuit having the highest insulation will approach in value to 10,000 volts, so that the insulation to ground of each circuit has to be able to withstand 10,000 volts.

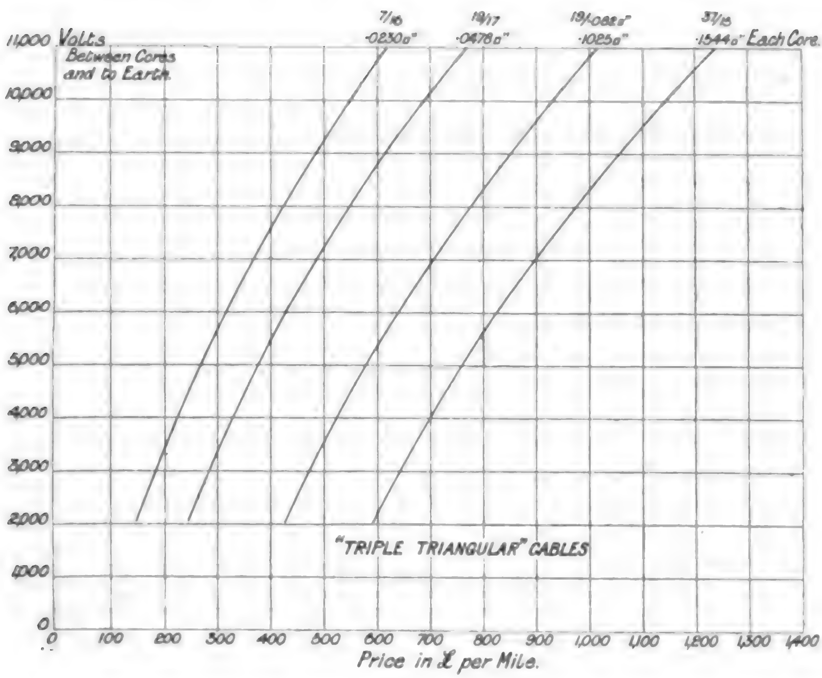


FIG. 1.

This increased insulation affects the cables by throwing out the diameter of the lead sheath and armouring, and will approximately increase their cost by some 10 per cent., or of the cable laid, including troughing, by some 7 per cent.

There are certain advantages which point to the desirability of earthing the neutral point, but there do not appear to be corresponding advantages to warrant not earthing. The increased cost of laying down a system such as we are considering, with no earth connection, is, however, not great; and may be taken as represented by a yearly charge of some £800. It seems, therefore, highly desirable that whatever may be our intention, that we should be able to either earth or not, as practice might prove desirable.

Other points of interest and importance which are considered are those relating to voltage, of generation, loss in transmission, current density in cables, the length of the cables, and several curves are given, with reference to these points.[1]

Fig. No. 1 gives the prices of 4 sizes of 3-core cables of the "Triple Triangular Diatrine" type, a single core having an area of ·023, ·048, ·1025, ·1544 sq. in. respectively in the four sizes of cables.

The cables are suitable for voltages ranging from 3,000 to 10,000.

From these curves it will be seen how rapidly the cost increases with an increase of voltage.

For the commercial consideration of the problem, it is necessary to ascertain the cheapest voltage at which the system can be worked, and to facilitate this, on Fig. No. 2 (which is practically a price list) 5 curves are plotted from the particulars on Fig. No. 1, giving the connection between area of copper and price per mile at 5 constant voltages. These two series of curves give between them the price of any 3-core cable up to ·2 of a square inch per core, and for any voltage from 3,000 to 10,000 between the conductors and to earth.

Figs. Nos. 1 and 2 are as stated only price lists, and do not readily give us what we require for the solution of our problem, which is to transmit a given number of kilowatts and to find the voltage which gives the cheapest cable.

Now there are two conditions, either of which can be fixed, but not both: they are density in the copper and per cent. drop.

In order to fix our ideas and have a starting point to work from, the curves in Fig. 3 have been plotted, giving the price per mile at various voltages: firstly, for a constant density of 1,000 amps. per sq. in.; secondly, for a constant drop of 1 per cent. per mile.

A certain k.w. load is taken, and the current found for it corresponding to various voltages. The area to carry this current, under the above conditions, is next found; the cable can be then priced from Fig. 2.

These curves in Fig. 3 show very clearly that there is a cheapest voltage for each number of k.w. to be transmitted. Above this voltage the price of the cable increases, due to increased insulation, and below, due to increased copper. These points of cheapest voltage are joined and they are seen to be on a straight line.

If it is inadmissible to work at 1,000 amps. per sq. in., and a lower density is necessary, any density other than 1,000 amps. per sq. in. can be obtained from Fig. 3, by moving along these straight lines; thus the curve for 2,000 k.w. at 1,000 amps. per sq. in. is also that for 1,000 k.w. at 500 amps. per sq. in., and so on, the percentage of drop being reduced in proportion to the reduction of the density.

Now the case of 1,000 k.w. interests us most. The curves for this show that the price for either 1,000 amps. per sq. in., or 1 per cent. drop per mile, is much the same, *i.e.*, £620 to £630 per mile. In the first case, however, 6,000 volts, and in the second 8,000 volts is the corresponding voltage of supply.

[1] I wish to thank Mr. J. Frith for assistance given me in the preparation of the curves, and Messrs. Callender, Glover, and the Helsby Company, for samples of cables they have lent me.

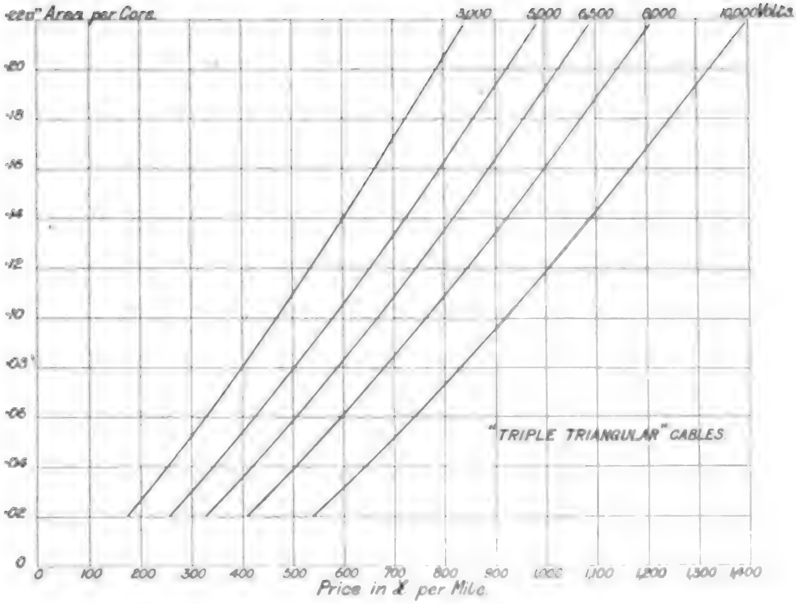

Area per Core.
3,000
5,000
6,500
8,000
10,000 Volts.
"TRIPLE TRIANGULAR" CABLES.
Price in £ per Mile.

Fig. 2.

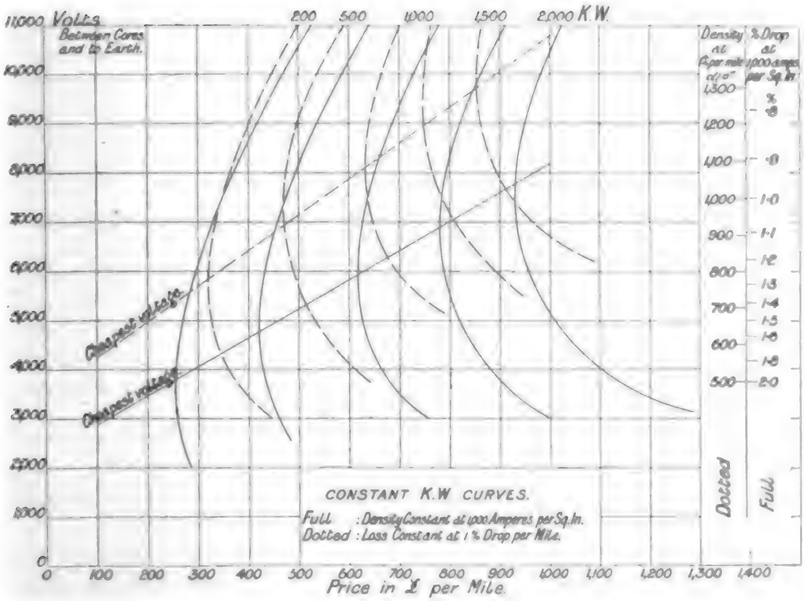

11,000 Volts
Between Cores and to Earth.
200
500
1,000
1,500
2,000 K.W.
Cheapest voltage
Cheapest voltage
CONSTANT K.W. CURVES.
Full : Density Constant at 1,000 Amperes per Sq. In.
Dotted : Loss Constant at 1 % Drop per Mile.
Dotted
Full
Price in £ per Mile.

Fig. 3.

The loss at 1,000 amps. per sq. in. is 1·25 per cent. per mile, and the density at 1 per cent. drop per mile is 1,080 amps. per sq. in. The two curves cross at a voltage of 7,500, which gives for the same cable 1,000 amperes per square inch, and 1 per cent. drop at a price of £640 per mile.

This is the price of the cable alone, the cost laid being approximately as follows:—

Cable delivered	£640
Digging trench at 1s. per yd.	88
Cast-iron trough, laying and casting up with bitumen, 3s. per yd....	264
Handling cable	70
Total cost per mile laid ...	£1,062

And it has been assumed that in large quantities a price of £1,000 per mile would cover.

Exact information as to the heating of this type of cable does not appear to be available, but it is probable that 1,000 amps. per sq. inch, giving a drop of 1 per cent. or 10 k.w. per mile is a possible figure for the maximum load on the cable, always bearing in mind that this maximum only exists for short periods, and that the cable is usually working at a much smaller loss and higher efficiency.

The curves show that for loads up to 1,000 k.w. per cable there is no need to go to 10,000 volts, the cables being actually cheaper per k.w. transmitted at considerably lower voltages.

In considering the cheapest size of cable to use, the cost of the energy lost should also be considered, but I would here point out that with these extra high-tension cables, the cost of insulation is so large that it is impossible to apply Kelvin's law, and make the cost of the loss equal the interest and depreciation on the cable; for this would work out to a loss much larger than the cable could dissipate in the form of heat.

A brief example will make this clear. It is shown elsewhere that at 7,500 volts and 1,000 amps. per sq. in., the loss in a mile of cable carrying a maximum load of 1,000 k.w. at 1 per cent. drop, and a load factor of 25 per cent. amounts to 15,000 $(\frac{5250000}{350})$ units per annum. This, at a works cost of ·415 pence per unit, equals £26 per year. The price of the cable laid is £1,000 per mile. This at 4½ per cent. interest, and 2½ per cent. depreciation equals £70 per annum. We should certainly hesitate to increase the loss in the cable to bring these two annual charges equal, so that the loss need only be considered as heating the cable and not affecting its price.

The maximum carrying capacity of any one main which the Board of Trade has consented to lately, is 1,000 k.w., and this seems to be sufficient for all ordinary purposes. But, for the purpose of linking two stations, it would be more economical to employ larger mains of say 2,000 k.w. capacity, and it is of interest to consider the relative cost. From the prices of cables given, three 1,000 k.w. 7,500 volt cables cost

£3,000 laid, whereas two 2,000 k.w. cables, allowing 50 per cent. more for laying, cost the same, but transmit 33 per cent. more energy.

We have heard it stated, amongst other places, in the Parliamentary Committee Rooms, that it is cheaper to carry coal to the district where the energy is required, and there to erect the generating station, than to transmit the energy electrically. This is an assertion which I do not think those who made it ever endeavoured to prove, and in practice it has nothing to do with the case. I have, however, carefully considered the matter, and have found that the cost of transmitting one and a quarter millions units per annum a distance of 10 miles, with a load factor of 25. per cent., and building a sub-station and converting it to the quality of current and pressure required, will add ·2 of a penny to the cost per unit.

These power companies do not anticipate supplying the largest towns with energy, but they do contend that they can generate, transmit, and convert, at a price which will enable the smaller towns to obtain advantages they now have not, and also to ensure a large demand from those requiring power.

Cost of sub-stations :—

When considering the cost of sub-stations, and the machinery with which they are to be equipped, it is necessary to make an assumption as to the uses to which the energy will be put, and the apparatus which is to be installed for conversion purposes, and below I give an approximate idea.

		Per cent. Rotaries.	Per cent. Motor Generators.	Per cent. Transformers.
15 per cent.,	Tramways and Light Railways ...	15	—	—
60 „	Motors	10	20	30
25 „	Lighting to authorised undertakers	—	15	10
		25	35	40

With regard to the load with which the sub-stations must deal, we have—

Four stations each 25,000	100,000 I.H.P.
At 84 per cent. efficiency	84,000 E.H.P.
Kilowatt capacity	62,660
From this latter figure 20 per cent. is deducted for unconverted current supplied from the power stations, leaving, say	50,000 k.w.

to be dealt with by the sub-stations.

In calculating the cost of the sub-station machinery, etc., I have taken the three types of converters in accordance with the percentages given above, and I have assumed 25 sub-stations, averaging 2,000 k.w. each.

	K.w.	Price per k.w.	Cost.
25 per cent., Rotary Converters with Transformers	12,500	... £4 ...	£50,000
40 per cent. Transformers	20,000	... 2 ...	40,000
35 per cent., Motor Generators ...	17,500	... 4½ ...	78,750
(The above prices include all starting gear.)			
			£168,750
Spare Plant and Boosters, add 20 per cent.			36,250
Switch Gear, Instruments, Cables, etc., at £500 per sub-station			12,500
25 Buildings at £500...			12,500
			£230,000

The rotary converters have been assumed for the traction load, and for such motors as can be conveniently supplied from the same mains. The transformers have been taken for the supply to 3-phase motors, and to such lighting as the users of the power may require, and for street lighting. The motor generators have been taken for lighting where direct current is required, and for such motors where advantageous.

With respect to the distributing mains radiating from the generating stations and sub-stations, the following is the capital expenditure which I have included for them :—

Distributing Mains	£350,000
Service Mains...	£200,000

TOTAL COSTS.

Capital Expenditure.

		62,500 k.w. installed.	Cost per k.w. installed. £
Four Generating Stations at £330,000 ...		£1,320,000 ...	21·10
Mains—Trunk	350,000		
Distributing[1] ...	350,000		
Service	200,000		
	...	£900,000 ...	14·45
Inspection and Service Boxes		10,000 ...	·16
Sub-stations, 25 each, 2,000 k.w. average, for 50,000 k.w.... ... ... Buildings, Rotaries, Motor Generators, Transformers, and Switch Gear ...		230,000 ...	3·70
Promotion Expenses, Engineering, Contingencies, etc.		60,000 ...	·96
Balance and Working Capital		146,666 ...	2·35
		£2,666,666 ...	42·72

[1] The distributing mains may be used for either high or low tension distribution ; high tension mains will in many instances have to be run from the sub-stations to smaller distributing stations, controlled by tramway companies and authorised undertakers.

Having considered the total capital expenditure, we can turn to the cost of generation, which is given in the following table, all expenditure being calculated on the basis of four power stations of 25,000 I.H.P. each, working with a 25 per cent. load factor.

Cost of Generation, with an annual output of 140,000,000 units :—

	Pence per unit.	Total.
Cost of Coal...	·128	£74,666
Oil, Waste, Water, and Stores	·04	23,400
Wages and Station Staff	·052	30,000
Repairs and Maintenance	·05	29,167
Rent, Rates, and Taxes	·05	29,167
Management, Directors' Fees, Salaries of Chief and Assistant Engineer, Office Salaries, Legal Expenses, Insurance, &c.	·025	15,000
Sinking Fund on four Generating Stations at £330,000 each—£1,320,000 at 3 per cent.	·068	39,600
	·413	£241,000

I will now consider the expenses in connection with the Trunk Mains, Converting Stations and Distributing and Service leads.

Upkeep and Superintendence of Trunk Mains and Sinking Fund.

Sinking Fund and Repairs on £350,000, at 4 per cent ...	£14,000
Superintendence and Wages	2,750
	£16,750

Converting Sub-stations :—

Cost of Sub-stations, £230,000, 3 per cent. Sinking Fund	£6,900
Repairs and Maintenance, 2 per cent.	4,600
Oil, Waste, Stores, etc.	5,000
Superintendence and Wages	18,750
	£35,250

Upkeep and Superintendence of Distributing and Service Mains :—

Sinking Fund and Repairs on £550,000, at 4 per cent....	£22,000
Superintendence and Wages	2,750
	£24,750

The Total Annual Expenditure being :—

Annual Expenditure at four Generating Stations, including Office Expenses, etc.	£241,000
Trunk Mains...	16,750
Sub-stations ...	35,250
Distributing and Service Mains	24,750
Annual Expenditure	£317,750

Analysis of total units sold :—

Each Generating Station	25,000 I.H.P.
Or for the four Stations	100,000 I.H.P.
This at 84 per cent. combined efficiency	84,000 E.H.P.
Or	62,660 k.w.
This at 25 per cent. load factor is ...	137,234,000 units per ann.
Say	140,000,000 units per ann.

Of this, 20 per cent. is generated as direct current and distributed from the power stations without conversion.

In calculating the lost energy in the trunk main, I have assumed as a basis 1,000 kilowatts transmitted 10 miles at 7,500 volts, with a drop of 10 per cent. or 1 per cent. per mile. Ten per cent. loss at full load represents a loss of 110 k.w. in 1,100 k.w. generated; but, working with a 25 per cent. load factor, this would be represented by 250 k.w. transmitted continuously. As the loss varies as the square of the current, the loss in this case would be one-sixteenth part of 110, or 7 k.w.

This, as a matter of fact, is the minimum loss which could exist, the actual loss being dependent upon the load curve on the main. The most extravagant rate at which the energy could be transmitted with the 25 per cent. load factor, would be to transmit 1,000 k.w. for 6 hours per day, which would represent a loss of 660 units per day; the minimum loss, on the other hand, being 7 k.w., or 168 units per day; and the average of the maximum and minimum losses, viz., 414 units per day, has been taken, or 41·4 units per mile per day.

Three hundred and fifty miles of trunk mains are included; this brings the loss in them to 5,250,000 units per annum. To calculate the loss in conversion, the plant in the sub-stations is assumed to be working at ¾ load, and the load to be divided between the various plant as already mentioned.

		Per cent.		Per cent.
Rotaries... ...	efficiency at ¾ load	= 90	Proportion of plant	= 25
Motor generators	" "	= 87	" "	= 35
Transformers	" "	= 97½	" "	= 40

This gives a combined efficiency of the sub-stations of 92 per cent. A loss of 2 per cent is taken for the distribution from the sub-stations, and for the direct current distributed from the power stations.

The total units sold are obtained in the following way :—

Units generated per annum	140,000,000
Less 20 per cent. distributed from power stations... ...	28,000,000
	112,000,000
Loss in high tension trunk mains	5,250,000
Delivered to sub-stations	106,750,000
Loss in sub-stations at 92 per cent. efficiency	8,540,000
	98,210,000

Add to this the D.C. units generated in power stations ...	28,000,000
	126,210,000
[1] 2 per cent. less in low tension mains	2,510,000
Units sold per annum	123,700,000

The above shows that the efficiency of transmission, conversion, and distribution, viz.: the percentage of units sold to units generated, equals 88·4 per cent.

Analysis of cost per unit sold, 123,700,000 units per annum :—

					Cost per Unit Sold.
Coal...				£74,666	·146
Oil, Waste, Water, Stores—					
	Generating Stations ...		£23,400		
	Sub-stations ...		5,000		
				£28,400	·055
Wages—	Station Staff ...	£30,000			
	Wages Trunk Mains	2,750			
	Wages Sub-station ...	18,750			
	Wages Dist. Mains ...	2,750		£54,250	·106
Repair and Maintenance—					
	Station		£29,167		
	Trunk Mains ...		3,500		
	Sub-stations... ...		4,600		
	Distributing... ...		5,500		
				£42,767	·083
Rent, Rates, Taxes ...				29,167	·057
Management, &c. ...				15,000	·029
Sinking Fund—	Stations		£39,600		
	Trunk...		10,500		
	Sub-stations		6,900		
	Dist. Main		16,500		
				£73,500	·144
				£317,750	·620

The total cost per unit sold having been obtained, we must next consider the maximum prices which the company is entitled to charge per quarter; and to make this clear I give the schedule of the Act

[1] The 2 per cent. loss in low tension mains may at first sight appear a rather low figure, but it must be remembered that these power companies will not carry on a retail business, and that in many instances small sub-stations will be built immediately adjoining, or as part of, the supply stations of authorised undertakers, in which case there will be no loss in low tension mains at all for which the power company will be responsible.

which settles this point. The scale of one or two companies varies somewhat, but the following may be taken as representative :—

A. To authorised undertakers.

(1) For any quantity not exceeding the equivalent of 100 hrs. of supply at the maximum power which has been demanded by him at the rate of 3d. per unit.

(2) For any further quantity exceeding the equivalent of 100 and not exceeding 200 hrs. of supply at such maximum power, at the rate of 2d. per unit.

(3) For any further supply exceeding the equivalent of 200 hrs. of supply at such maximum power, at the rate of 1d. per unit.

B. To persons other than authorised, 20 per cent. in excess of the above rates.

TABLE SHOWING MAXIMUM RATE OF CHARGE AND LOAD FACTOR.

Hours per quarter of maximum demand.	Equivalent Load Factor.	Price per Unit in Pence. To authorised undertaker.	Price per Unit in Pence. To others. 20 per cent. extra.
100	4·6 per cent.	3	3·60
200	9·0 ,,	2·5	3·00
300	13 ,,	2·0	2·40
400	18 ,,	1·75	2·10
500	22 ,,	1·60	1·92
600	27 ,,	1·50	1·80
700	31 ,,	1·43	1·72
800	36 ,,	1·38	1·66
900	41 ,,	1·33	1·60
1,000	45 ,,	1·30	1·56
1,100	50 ,,	1·27	1·52
1,200	54 ,,	1·25	1·50
1,300	59 ,,	1·23	1·48
1,400	64 ,,	1·22	1·46
1,500	68 ,,	1·20	1·14
1,600	73 ,,	1·18	1·42
1,700	77 ,,	1·17	1·41
1,800	82 ,,	1·17	1·40
1,900	86 ,,	1·16	1·39
2,000	91 ,,	1·15	1·38
2,100	96 ,,	1·14	1·37
2,190	100 ,,	1·14	1·37

It will be seen from the above table that with a 25 per cent. load-factor the maximum rate of charge

To authorised undertakers is ... ... 1·55d. per unit

and to others (plus 20 per cent.) ... ... 1·87d. ,,

In considering the financial result of the complete undertaking, an average charge of 1·1d. per unit has been assumed. This is very much lower than the company is entitled to ask ; but as, during the first few years of working, the total costs will exceed ·62d. per unit sold (which is the figure arrived at), it will be desirable at first to charge in accord-

ance with the scheduled rates, the charge being subsequently reduced as the cost of production decreases.

We have now lastly to consider the financial result on the basis of the calculations which are before us.

The total units per annum sold equal	123,700,000
Which, at a charge of 1·1d. per unit, yields a gross revenue of	£567,000
The annual expenditure is	317,750
Leaving a profit of	£248,250
And this is equal to :	
4½ per cent. on £666,666 debentures	£ 30,000
and 10·9 per cent. on £2,000,000 share capital ...	218,250
	£248,250

This result is one which is in every way satisfactory, and the investigation of the problem has confirmed my opinion that there is a great future before these power companies.

Although my examination of the subject, as far as this paper is concerned, has now ended, many points remain which might with great advantage be mentioned. Some of these, I hope, will be brought out in the discussion. There is, however, one point that has impressed me in investigating this question, and I desire to say a few words upon it.

The capital of these power companies is somewhat proportionate to the areas they have power to supply, and the Yorkshire Company, which I have taken as an example, has an amount slightly over 2½ millions to deal with, and an area of 1,800 square miles ; and provision in their parliamentary estimates has been made for 100,000 I.H.P. Now this horse-power can be successfully dealt with with this capital ; but there is no doubt in my mind that the stations will be fully loaded long before the demand for power has been satisfied in the district, and that ultimately additional capital will have to be raised, the stations enlarged, and some new ones erected. This development, which I consider certain, would result in the first instalment of 100,000 I.H.P. being connected up to customers situated at no great distance from the stations. The cost per k.w. for mains would, therefore, not be excessive, and each new station or extension, including plant and mains, could be put down for approximately the same sum per k.w. as estimated.

Mr. EARLE : After I had seen this paper in print I found that there were several points which might with advantage have been mentioned, and that some rearrangement would have been desirable. With regard to the question relating to the cost of carriage of coal *versus* the cost of transmitting energy electrically, I desire to ask Mr. Wordingham to prove the figures which he gave in evidence before the Parliamentary Committee in connection with the Lancashire Power Bill ; the figures given in his printed evidence being that when transmitting 1,000 k.w.

twenty-five miles with mains costing £1,800 per mile and with a 25 per cent. load factor, the interest charges alone on the cable equal ·49 pence per unit, and that the cost of carrying fuel equals only ·059 pence per unit.

Mr. Wordingham.

Mr. C. H. WORDINGHAM (*Chairman*) said that he could speak in all the capacities enumerated by Mr. Earle, having criticised power schemes as a professional witness, as an opponent on behalf of corporations, and as a conscientious objector, and he was further induced to take part in the discussion as he had devised one of the earliest schemes of the kind in this country to take practical shape. So far he was still dependent upon other food than his own words, not any of which had he found it necessary to eat.

Mr. Earle had thrown down the gauntlet, and he was quite prepared to take up the challenge. Mr. Earle said that in opposing one of the power schemes, he (Mr. Wordingham) had taken 10 per cent. interest on capital. The print of the evidence to which Mr. Earle referred must have been incorrect, as what he had said, and what he had written in his proof, was "that the interest on capital was 5 per cent. and the rate of depreciation on the mains was 5 per cent."; and he could not consider that either of these figures was excessive; indeed, they tallied with Mr. Earle's within one per cent. It so happened that he had that very day looked up his proof in order to refresh his memory, and, far from disowning his own figures, he desired to use them on the present occasion. He would refer to page 897 of Mr. Earle's paper in which he stated that the cost of transmitting 1¼ million units per annum a distance of 10 miles with a load-factor of 5 per cent., including transformation, would add 0·2d. per unit. Mr. Wordingham maintained that this cost was greatly in excess of the cost of carrying the coal. Assuming that coal cost 1d. per ton per mile for carriage, and 6d. per ton for upkeep of wagons, together with 1s. per ton for carting, the total cost for transmitting the quantity of coal corresponding to the case Mr. Earle had taken worked out to 0·025d. per unit, so that electrical transmission cost eight times the carriage of coal. Another point that Mr. Earle had attacked in the evidence given by the speaker to which reference had been made was the price taken for the mains. Mr. Earle had assumed £1,000 per mile, whereas the speaker had assumed £1,800. Perhaps the difference was to be accounted for by Mr. Earle having taken a current density of 1,000 amperes per square inch, whereas he (Mr. Wordingham) had taken a current density of 600. He could only express the hope that when Mr. Earle ran his rotatory converters, he would not have to come down to the lower density.

Having replied to Mr. Earle's challenge, he would turn to the general question, and, in the first place, he was glad to see that Mr. Earle demolished the fallacy that water-power was much cheaper than power developed from coal. In many cases it might actually be dearer, on account of the great cost that usually had to be incurred in utilising the water as well as the payment required for the water rights.

There was, however, another fallacy that underlay much that was

Mr. Wordingham.

said about these power schemes, a fallacy which he did not think had been pointed out. Comparison is made between power production here and on the Continent and in America, and it is stated, very truly, that power can be produced as cheaply from coal as from water-power, and the inference drawn is that large power schemes will therefore pay as well here as abroad, if not better. The fallacy underlying this argument is that abroad there is no choice; that, whereas in England coal can be obtained cheaply in any district, abroad, in many places, there is either no coal or it can only be had at prohibitive prices. It seemed to him that there was no analogy between the power schemes abroad and the proposed power schemes here, and it by no means followed that because water-power abroad had met with a wide field, power derived from coal and distributed over wide areas from single stations would be in great demand here. Coal, as he had already shown, could be transmitted so very cheaply mechanically, that there was no necessity to transmit it electrically, and it could be burnt with great economy in small stations. By the use of gas engines, a Board of Trade unit could be obtained with substantially less than 2 lbs. of coal, even when working on a very small scale. In point of fact, Mr. Earle's own firm had recently guaranteed, under a specification of his (Mr. Wordingham's), to give a Board of Trade unit for 16,000 British thermal units of heat, which corresponded, if any ordinary producer were used, to 1·8 lb. of coal burnt in the producer. He had every confidence that the guarantee would be fulfilled. It would have been interesting if Mr. Earle, besides enumerating the schemes abroad, had given a few of the financial results attained, and, also, if he had stated whether interruptions in supply were frequent or serious. On page 889 figures were given which were no doubt useful in Parliamentary estimates, but to him they were not very convincing. It might well be that in a given radius there were mills requiring two million horse-power to drive them, but he believed that if there were, and they were ever driven electrically, and he were to see them, he would by that time be a very old man.

Mr. Earle had stated that the local authorities had opposed the power schemes, and he implied that they did so from selfishness and because they did not like competition. This was not the case; the local authorities did not object to competition. What they did not like was unfair competition, and, if the Bills in their original form had passed into law, the local authorities would have been most unfairly treated. What was sought, originally, was to give the companies power to select all the plums, leaving the refuse to the local authorities; that is to say, the companies could select their consumers, while the local authorities must supply any one who chose to make the demand. It was quite true that the local authorities were now fully protected, but the local authorities had only themselves to thank for this protection.

On page 888, reference was made by the author to small towns, and to the benefits that they were to derive from the power stations. He very much questioned whether much work would be done in this direction by the companies, and he altogether failed to see how the

Mr. Wordingham. companies would make this class of work pay. If they obtained these small authorities, he did not see how the large sub-stations they were hoping for would be obtained. They would have to work on a much smaller scale, with corresponding increase of cost.

He desired to refer particularly to one point in which he thoroughly agreed with Mr. Earle, namely that portion on page 892 in which he pointed out the importance of the schemes paying as they went along, and the necessity of not overburdening them with capital in the first instance. This was a most vital point and one frequently lost sight of. Undertakings were frequently launched on too large a scale, and failed in consequence, whereas, had a modest beginning been made, they would have proved a success.

In conclusion, he desired to emphasise the fact that he was not in any sense an opponent of power schemes. On the contrary, he belived that some of them would succeed, but he did not believe in them all. It was necessary that the conditions should be favourable. As a general principle, great advantage was gained by concentration, but the crux of the whole matter was the load-factor. If, and so far as, the load-factor could be improved, there was a gain, but without this improvement there was practically none, and he very much questioned whether areas of such large extent as those having a twelve-mile radius would be suitable. He thought the radius should be much shorter. He believed that much harm had been done by the use of the term "supply in bulk." It was altogether misleading, and implied that the power companies could generate more cheaply because somebody else undertook the distribution; whereas all that was done was to divide the responsibility at a given point. Diminished cost of production does not depend to any appreciable extent on the increased scale, but on the improved load-factor.

(*Communicated.*) Mr. Earle having sent me an extract from his paper, in which he directly asks me to prove certain figures which I gave in evidence before the Parliamentary Committee in connection with the Lancashire Power Bill, I have pleasure in complying with his request. I have before me the original typewritten proof of my evidence which was given before the Committee. I assumed that a 1,000-kilowatt main would cost £1,800 per mile, this being the price actually paid for such mains in Manchester at that time. The cost of 25 miles of such mains would therefore be £45,000, and the annual charges are thus calculated in my proof :—

"Taking interest charges on this (£45,000) at 5 per cent., omitting sinking fund, which has not necessarily to be paid by a limited company, and taking depreciation at 5 per cent. per annum, a very moderate sum for high-pressure mains, I find that the annual cost for these two items amounts to £4,500, without allowing any sum for ordinary repairs and upkeep. Assuming a load-factor for the main of 25 per cent., which is an exceedingly high one, an ordinary lighting station working only at 10 to 12 per cent. load-factor, the number of units transmitted per annum through this main would be 2,190,000, and the interest charges would thus amount to 0·49d. per unit.

"Assuming that 3 lbs. of coal were required per unit transmitted,

the total weight of coal required for the production of these 2,190,000 units would be rather under 3,000 tons. Now the cost of carriage of coal by rail is about 1d. per ton mile for distances not exceeding thirty miles, and to this must be added 6d. per ton for upkeep of wagons, and 1s. per ton for carting from the railway station to a local generating station. Hence the total cost for mechanically conveying the fuel from the pit at which the Company's (Lancashire Power Company, who were promoting the Bill) generating station is assumed to be situated to the point to which the electrical energy is transmitted would be about £540 for the fuel, corresponding to 0·059d. per unit transmitted." Mr. Wordingham.

In spite of its being somewhat lengthy, I have given the above extract in full, so that there may be no doubt as to what my evidence actually was. I do not think I could more conclusively prove my contention that mechanical transmission in the case selected was many times cheaper than electrical transmission, and it is for Mr. Earle to assail the figures if he can.

Mr. W. P. J. Fawcus said he was one of the promoters and was now a director of the two largest of these power schemes, the Lancashire and the Yorkshire, and had therefore naturally a belief in their future. Mr. Wordingham had stated that his opposition to the Lancashire Power Scheme was based on his objection to the Power Companies picking out best districts and leaving the worst; such, however, could not be said to be the case, as this company applied for the whole of the county of Lancashire south of the Ribble. Mr. Fawcus.

Mr. Wordingham had also criticised the load-factor which Mr. Earle expected to obtain, but he probably had not given due weight to the fact that the principal users would be power-users. Mr. Fawcus himself had had some experience of the load-factor obtained in a power-supply station as at Tafford Park; their worst load-factor so far had been 45 per cent., and they had for a short time the abnormal load-factor of 70 per cent. There were, however, special conditions connected with the user of power at this station which might make it hardly a fair comparison with power schemes covering a wider area.

Mr. Fawcus could not quite agree with Mr. Earle in taking his pressure of transmission so low; he appeared to expect that the Board of Trade standard of insulation would have to be rigidly adhered to. By this standard 30,000 volts pressure would involve a thickness of insulation of one and a half inches, which would be manifestly absurd. As a matter of fact, several gentlemen were present in the room who had been with him when a test 35,000 (the maximum pressure available) had been put upon a piece of cable with less than one-third of an inch of insulation without breakdown, and he had since received a certificate to the effect that a similar cable of Messrs. Glover's manufacture having less than one-tenth of an inch of insulation had been tested by Dr. D'Arsonval in Paris up to 55,000 volts without breakdown. There was little doubt that as results like these were now readily obtainable, the Board of Trade would alter their standard and so enable high-pressure cables to be manufactured at a very much lower price, the reduction in the thickness of the insulation greatly

Mr. Fawcus. cheapening the finished cable by decreasing the weight of the lead envelope.

Mr. Fawcus could quite bear out the author's estimate of 1s. per yard for laying, as the majority of the mains of the power companies being feeders linking together the various centres of population would pass through country roads with a comparatively small proportion of street work. The Altrincham Electric Supply Company, which had a mixture of country roads and streets with a preponderance of the former, had for many years a contract with a local contractor for the whole of their roadwork at sixpence per yard.

Mr. Highfield. Mr. J. S. Highfield said: It was good to have a paper that dealt with very broad questions. His remarks had been in some part forestalled by those of Mr. Wordingham and Mr. Mountain. He agreed with Mr. Mountain that these power schemes could not, on the present lines, and at a remunerative rate, supply very large single consumers such as mills and electrolytic works at a great distance. If the stations were to be put in suitable positions in the open country, on sites adjacent to a river or good coal supply, new works could be established near the stations, so that the distribution would be very short, there might then be a large field for the supply. There would be an enormous field for the supply of current for electrolytic purposes in the very near future, and electricity would be used in great quantities for new works operating new processes, and it would be of great advantage to such works to have their capital kept as low as possible by obtaining their electric energy from a supply company.

He thought that Mr. Earle's figure for load-factor was by no means excessive, nor was the estimated output too high. He would take a particular case that he had to deal with lately; it was a large mill with a very large amount of power employed. The total units that the works would take if it were driven electrically would be at least 20,000,000 per annum; the total cost would be 0·3d. or 0·4d. per unit on a load-factor of 70 per cent. The power company could not possibly supply energy to such a concern unless the transmission charges were enormously less than 0·2d. per unit.

All Mr. Earle's figures were worked out on the assumption that underground cables would be used, and although Mr. Earle only refers to it incidentally, he (Mr. Highfield) did not see why overhead feeders should not be used; there was no objection from an æsthetic or a practical point of view. He thought overhead feeders could alone make the power companies commercially successful. He was trying to consider the whole question from the power company's point of view, because they, as electrical engineers, were desirous of seeing the industry extended in every possible direction.

Another good source of business as well as new works erected near to the power station, would be the smaller isolated works working with a rather low load-factor.

There was another field in collieries. He had equipped at St. Helen's, he believed, the first colliery worked in this country entirely electrically, and one that does not burn an ounce of coal except to warm the engine-house; the energy was used for cutting, hauling, and

winding. It was supplied from the Corporation mains, and was exceedingly successful and economical. Comparing the figures of this colliery and one worked by steam, the former at 2d. per Board of Trade unit works out at one-fifth of that worked by steam. These were small collieries, but electric power could be supplied to much larger collieries. Colliery managers or companies were very wasteful of their coal, and, from the way they operate their engines at present, it would pay them to take a supply of electricity from outside. Mr. Highfield.

It must be remembered that a great many collieries start for a short time, and when the market fails they shut down. They would make suitable consumers for a power station, for it would not pay them to put down their own plant in the first instance.

Another case would be to supply very small towns, that could be better supplied from a central sub-station than from their own main station, which it would not pay towns where the population was exceedingly small to install. But if there were large works, and these took the initiative and put down plant not only for their own use, but also to supply the town, that would probably be the best solution. If, however, the large works would not take the initiative, it would be cheaper for the small towns to take their supply from a power station than to make it themselves.

With regard to the cost working out to 0·4d. per unit, this could no doubt be done at a 25 per cent. load-factor on 140,000,000 units. The total cost at their works (St. Helen's) was 1·18d. per unit with one million units. He, therefore, had no difficulty in accepting Mr. Earle's costs. He would like to hear the exact scale of charges; 1·1d. was merely an average price. He gathered that a sliding scale would be adopted with, say, 2d. per unit for 200 hours' use, and ½d. or ¾d. after that.

Mr. A. B. MOUNTAIN said he would like to thank Mr. Earle very much for his paper, which put the case for the supply of electricity in bulk in a more businesslike light than it had ever been put before any committee of the House of Commons, and he wished that the opponents of the Bills had had such clear statements as Mr. Earle had given to oppose; but after going carefully into Mr. Earle's figures, he could not help thinking that the title of the paper should be altered to Mr. Earle's dream. Mr. Mountain.

Referring to page 888, he thought Mr. Earle would agree with him that the figures he had given were wrong. As an example, Huddersfield was given with an output of 900,000 units, whereas with the traction and lighting load combined, it was 2½ million units approximately. He had therefore assumed, for the sake of argument, that the output of the towns named by Mr. Earle would be equal to 20 million units. He had also left out of the paper a considerable number of local authorities with works with a population of approximately 150,000, which would reduce the population in the area of 1,630 square miles to about 900,000. It should be remembered that corporations had in some cases for 10 years been doing all they could to sell electricity in the small area mentioned by Mr. Earle, and although they were dealing with a population of 1,600,000, they had only succeeded in selling 20

Mr. Mountain. million units, yet Mr. Earle supposed that he was going to sell 140,000,000 units over an area of 1,630 square miles, and with a population of only 900,000. It must not be forgotten that in this area a very considerable portion of the ground was occupied by sheep farmers, horse breeders, and poultry runs.

On page 897, Mr. Earle estimated that the cost of delivering energy from the works to, say, a mill 10 miles away would equal 0·2d. per unit. He would like to give them some actual figures. It was costing him to get coal from a pit, approximately 10 miles away, 2s. 2d. per ton, but for the sake of being perfectly fair and allowing for contingencies, he would assume 2s. 6d. per ton. This figure worked out for the cartage of slack, assuming 5 lbs. of slack per unit, at 0·06d. per unit. If the mill-owner paid as he was doing, 3s. per ton at the pit, it would work out at 0·08d. per unit, so that it will be seen that the figure mentioned by Mr. Earle would absolutely prohibit the supply to the mill-owner, who could generate his power more cheaply by using coal at his mill than by using electricity from the company.

He considered Mr. Earle's estimates were very fair, and that there was practically only one point with which he disagreed, that was his assumption of the load-factor. He had allowed for nine plants, and yet he had assumed for two classes of generating plant, one for continuous current and the other for alternating, and yet he had only allowed for one plant as spare. He thought that, upon reconsideration, Mr. Earle would agree that he had estimated his output on too large a proportion of his plant. In conclusion, he would say that unless the power company were able to supply large mill-owners at something below a halfpenny per unit, he did not think there was the slightest chance of their being able to pursuade them to take out their existing engines that were in many cases doing most economical work. It should not be forgotten that for years corporations have been charging 1d. per unit, and at that price they could not touch the large mill-owners. It was quite obvious that Mr. Earle could not supply an immense number of small consumers for power purposes, because in the outer districts there were none.

Dr. Panton. Dr. J. E. PANTON said: He joined with Mr. Wordingham in opposing one of the power schemes, and therefore would come under Mr. Earle's ban in the same manner. He agreed with Mr. Earle in one thing in his paper. It was that many of the witnesses in the power schemes would have to eat their own words, especially such witnesses favourable to the schemes as promised to supply power with a 100 per cent. load-factor at 0·174d. per unit. Mr. Earle's figures for output were, in his opinion, far too ambitious, and he (the speaker) thought that 100,000,000 units per annum would be the maximum that could be sold from a group of stations with 60,000 k.w. of plant installed. He would like to remind Mr. Earle that there had been a visit of the Institution of Electrical Engineers to Berlin, and they were shown over the Berlin undertakings, comprising six stations having a total of 84,000 k.w. of plant installed. At these stations their maximum load was 60,000 k.w., which is equal to the total plant installed in the scheme under discussion. There the output was only 50,000,000 units per annum, and they sold

at an average of 2·87d. per unit. As Mr. Mountain said, he thought they would not be able to drive large mills. In Bolton, many of the large mills developed their power from steam at something under 0·4d. per horse-power hour. He did not think electrical supply undertakings could expect to compete on those terms; besides which, most of these industries require steam for various other purposes in manufacture, and, therefore, they would have to use boilers in any case. Dr. Panton.

Mr. Earle suggested a 50 per cent. load-factor for tramways, whereas the Bolton Electricity Undertaking sold two thirds of their output for tramway purposes, and the load-factor for tramways alone was only 25 per cent. The charges for power in Bolton were from 2d. for intermittent users, to 1·35d. per unit for consumers using the supply forty-eight hours per week, and at that price consumers looked askance at them. He thought they could bring the price down, but not so low as an average price for tramways, power, and lighting, of 1·1d. per unit. He would like to know how Mr. Earle arrived at his charges for power supply. What was to be his top price, and what was to be the "bed rock" bottom price for motive power? He hoped Mr. Earle would realise his dream, to a certain extent, but he feared the realisation would be but a caricature of the dream itself.

Mr. JOHN SHAW said: Every contribution to this question of distributing electrical energy was important from whatever source it might come. He was pleased that Mr. Earle had become a disciple to multiphase currents at any rate so far as South Yorkshire was concerned, as last year he thought Mr. Earle was preaching the doctrine of continuous current. Half a convert was better than none at all. He, Mr. Shaw, agreed with Mr. Mountain that it was not likely they would get any large users of power to take electrical energy at a price beyond 1d. per Board of Trade unit. At the present time gas supply can be had at an exceedingly cheap rate, and you can put down a plant and generate your own electricity with gas engines as prime motors, at a cost below ½d. per Board of Trade unit. In fact, he, Mr. Shaw, had a plant in his mind where the cost of generating current was below 0·4d., and that with a by no means large plant. The cost of gas was, however, in this instance, very low. He felt certain that colliery owners were only too wide awake to their interests, and would not be likely to pay 1d. per unit for electrical energy when they could put down their own plant and obtain current at a lower cost. Mr. Shaw.

One of the speakers had described the paper as Mr. Earle's dream; he, Mr. Shaw, believed in dreamers—they very often brought their dreams down to solid and accomplished fact.

With regard to the cost of cables and of laying, he, Mr. Shaw, felt sure that Mr. Earle had not provided sufficiently for contingencies; he would rather take the figure given by Mr. Wordingham of £1,800 per mile as a basis of calculation than the figures accepted by Mr. Earle. As to the cost of laying the Altrincham cable which was mentioned as an example, this was laid in a shallow trench and in a light sub-soil, in fact was laid in the open ground, but when it was necessary for the cable to be laid in an iron culvert and a deep trench cut for it, the cost is bound to be much higher. He did not think it was possible in

Mr. Shaw. South Yorkshire to cut trenches at an average of 1s. per lineal yard; they would find all sorts of difficulties to be encountered, and he should be inclined to put the figure at 2s. instead of 1s.

He had nothing but praise to offer for the valuable contribution of Mr. Earle. They wanted much light upon the subject of transmission. Some were disciples of one method and some of another; we required full, free and open discussion upon the question. He, personally, had had experience of three-phase as well as of continous-current transmission, but he thought continous-current machinery would be in use when they had passed away. He was of opinion that Mr. Earle, in submitting his proposals with respect to the South Yorkshire power schemes, had taken far too rosy a view of things, because they were based purely on estimated figures and did not provide sufficiently for contingencies that would certainly arise.

Mr. Taite. Mr. C. D. TAITE said: With regard to the load-factor, of course there might be some special conditions with which Mr. Earle would have to deal, but he was calculating on very long-hour consumers. To take tramways as an instance, a 50 per cent. load-factor represented a working day of twelve hours at full load during seven days a week, whereas the ordinary tramway load did not represent more than a 25 per cent. load-factor; then again, a 30 per cent. load-factor for motor work meant that the factories were to run full load for fifty hours a week, which was a very high figure, and one that was not often reached by ordinary works. Although such works might make fifty hours a week, they were not working at full load the whole time. With regard to the effect which the load-factor had on the financial results, an easy calculation would show that if the load-factor were reduced to 20 per cent., as he feared it would be, seeing that a town like Bradford, which had got quite the largest motor load of any town in this country, only reached 14¼ per cent., and Bolton, with 60 per cent. of its power supplied to its tramways, only reached 18¼ per cent., then the income would be reduced by one-fifth, with only a very small reduction in the working expenses, and the Company would only be able to pay, under the most favourable conditions, 6 per cent. on the original capital. Again, on what he (Mr. Taite) considered a very high load-factor, Mr. Earle had calculated on receiving 1·1d. per unit sold, but it was quite evident that if Mr. Earle's expectations with regard to load-factor were realised he would not get such a high price as 1·1d. per unit, as concerns working such long hours could generate much more cheaply for themselves.

Mr. Clirehugh. Mr. S. V. CLIREHUGH said he must congratulate Mr. Earle on having presented the Institution with so admirable a paper. One of the speakers had called it a dream, but this was a most unfair name. It should more justly be termed an "intelligent anticipation" of the near future. He had never listened to such pessimistic arguments against power distribution by means of electricity as those advanced by the speakers that evening. The majority seemed to be under the impression that the electric supply business of the future was to be conducted on the lines that local authorities in this country had carried it on in the past, a business practically confined to a supply for lighting

Mr. Clirehugh

and tramway purposes. They were, however, obviously on the verge of something very different, and something which would give rise to conditions of which those who had been merely concerned with that form of supply had no conception.

It seemed to him that a large amount of the discussion had turned on the question as to whether it was cheaper to cart coal or distribute electrical energy. This did not seem to be pertinent to the paper. People purchased coal to produce energy, but they would infinitely prefer to buy the energy they required in a more convenient form such as electricity, and they were prepared to pay a higher price for obtaining such supply. The question was, would people pay a sufficient price to enable the coal energy to be transformed into electrical energy, and to be transmitted to the requisite point? His answer to that was yes! In Trafford Park there was a power-station to which his firm were engineers, and he would give a concrete example of the saving which could be effected in certain manufactures. The power-station supplied the Lancashire Dynamo and Motor Company with electrical energy at such a price that at 1¼d. per unit the total annual cost to the Company was only £2 12s. per I.H.P. The maximum power the Company required to drive their works was 330 I.H.P. This price of course compared most favourably with the cost per annum of an I.H.P., which it was usual to assume was £5 in Lancashire. He had pleasure in assuring the meeting that under such conditions 1¼d. per unit was a very satisfactory price to the power-station. He believed that 90 per cent. of the machine-shops in Lancashire would gladly accept such an offer.

Some speakers seemed to think that if they took the I.H.P. of a mill engine and multiplied it by the working hours in a year, and then assumed that a Board of Trade unit was equal to 1⅓ H.P., they would arrive at the number of units which would be used per annum by such a works. Assuming that 1 k.w. applied direct to the machine to be driven was equivalent to 2 I.H.P. generated in the basement, which was an assumption that even the most obstinate opponents must admit, at 1d. per unit, even multiplying by the whole number of working hours per annum, the equivalent cost per I.H P. per annum was only £5, and there was thus found the whole saving effected by the fact that when a machine was not actually working it was costing nothing for power, and when it was working it was only consuming energy in proportion to the work it was doing. This saving of course varied according to the manufacture dealt with, but in practically every trade other than spinning and weaving it was not less than 50 per cent.

Mr. Earle's average load-factor of 25 per cent. had been criticised. At Trafford Park the load-factor taken every week had never been below 40·3 per cent. There were about 15 consumers. They supplied the Ship Canal with 300 H.P. for various purposes, such as cranes, etc., in addition they supplied saw-mills and earthenware works, cable and machine works, and the explanation of the good load-factor was that their consumers found electricity on tap so convenient a source of power that they frequently ran machines, which were busy, for two shifts a day, a thing which would be uneconomical if they had to keep

Mr. Clirehugh.

an engine and boiler running to drive them. The Trafford Company received an average price of 1·1d. per unit, and although their load was very small (1,000 I.H.P.), this price paid them very well indeed.

With regard to the cost of production given in the paper, he (the speaker) thought there was only one item open to criticism, viz., the cost of coal. He doubted whether without recovering the by-products of the coal a unit could be produced for 0·128d., which, at 7s. per ton, equalled approximately 3 lbs. It would not seriously modify Mr. Earle's results if this amount were substantially increased. He did not, however, think that in power schemes of this description it should be forgotten that by employing Mond gas the ammonia could be recovered from the coal and be made to yield a very handsome profit. He (the speaker) had it on the highest authority that with sulphate of ammonia at its present price it was possible to sell Mond gas in large quantities at ½d. per 1,000 cubic feet, which, properly applied, would give 10 H.P. for one hour. This was another argument in favour of large central stations, because to obtain such results it would be necessary to gasify a minimum of ten tons of fuel per hour continuously.

Mr. Earle had overstated the load-factor derivable from tramways, but the paper dealt so ably with one of the most important problems of the future that the author may well be excused if he allowed one or two trivial errors to creep in. He thought that, taken all round, the estimates contained in the paper were most reasonable and likely of realisation in the near future.

Mr. Sturgeon.

Mr. John Sturgeon said: Mr. Wordingham had had a good deal to say about so-called "fallacies" in Mr. Earle's paper. He should like to draw attention to one fallacy of Mr. Wordingham's into which even Mr. Earle seemed to have fallen, viz., that the 1,500,000 inhabitants of the towns given in the list on page 888 already had a supply of electricity for power. They had nothing of the sort. Some few of them might have the benefit of a limited supply for a few hair-brushing machines and the like, but nothing that could be described as even a limited supply for manufacturing purposes. When he, Mr. Sturgeon, was making investigations in the case of the Yorkshire scheme as to the number of power users and the amount of power demands in the district, all he could trace supplied direct by (for instance) the Leeds Corporation for power purposes was about 130 H.P., as against about 5,000 H.P. in private electrical installations, so far as he was able to make out in the short time available, though probably a much larger amount than 5,000 H.P. would on further investigation be found to be used by engineers, mill-owners, printers, and others in the town, who were supplying themselves from their own separate electrical plants at much less cost than the Corporation could produce it for. A glance at the load-factors of the towns named would be sufficient to prove this. An ordinary factory load was about 30 per cent., and the average combined load-factor of a number of factories would be much higher than that of any single factory. But Leeds had only 11·28 per cent. load-factor: this was obviously almost entirely for electric lighting. There was no margin there for any manufacturing load worth mentioning. Their

tramway load was not included in this, that being an absolutely separate department confined to the tramways alone, and not applied to manufacturing or other purposes outside the tramways. The electrical supply of these large towns was almost entirely limited to lighting, and even then it only supplied a fraction of the 1¼ million of inhabitants, and at such high rates that only the wealthier ratepayers could avail themselves of it. Mr. Sturgeon.

With regard to the load-factor at the generating station, he thought that Mr. Earle, in his desire to avoid over-estimating, had taken it exceedingly low, and that he had also underestimated the proportion of users of motors in allowing only 60 per cent. of the total load for motors, 15 for tramways, and so much as 25 per cent. of the total load for lighting. No doubt the result was good enough even on that basis, but it was much lower than it would work out. Within a radius of five miles from the Methley power station there were 75 collieries, which collieries were working night and day, but of course not always continuously, because now and then one colliery had its "play Monday," another its "play Tuesday," and so on as the case might be. Still, 70 per cent. might fairly be relied on as a load-factor for collieries about that district, and of course the combined load-factor at the generating station would, by the law of averages, come out much higher, and it was certain to increase by the introduction of improvements. Some might have seen in the *Daily Mail* that morning an account of the extent to which electrical coal-cutting machinery and other mining machinery worked electrically was being used abroad, and he believed there would be plenty of demand from the collieries alone within five miles south of Methley to absorb nearly the whole of the output of which the Methley station would be capable. He felt confident that that station would produce a load-factor of not less than 70 per cent. even when watered down by the lighting load from local authorities; Wath, which was in the centre of a rich colliery district, nearly the same; Thornhill, which had 63 collieries within five miles radius, but more of ordinary factory load and some tramways, about 50 per cent.; and Bingley, which would be mostly factory and tramway load, about 35 per cent., and that Mr. Earle's estimate of 25 per cent. general load-factor might be safely doubled and still be on the safe side. It seemed to him that we were so much accustomed to lighting load in this country as to render it difficult to appreciate the effect of manufacturing loads, especially in colliery districts and where chemical industries were carried on, and so we kept continually harping on electric lighting results and overlooking the fact that this was a *power* supply scheme we were dealing with.

With regard to the cost of laying mains, they could get way-leaves throughout the whole district along the canal towing-paths and railway embankments. The canal companies fought hard for them to have the right to supply them included in the Bill, and the railway companies also, and the cost of laying mains along towing paths and railways would be very small indeed, and greatly reduce the general average cost.

With regard to the assertion that it would be impossible to get mill-owners to pay as much as 1d. per unit, he happened to have investi-

Mr. Sturgeon.

gated the amount of horse-power used at some of the mills, and came to the conclusion that, when they came to reckon up the intermittent work and the saving of power in driving shafting and cost of running the various small engines in the mill, they would find the actual H.P. in use might be reduced in most cases by almost one-half; so that although the unit H.P. might cost more on the electric system, yet the total amount of H.P. required was so much less and the collateral advantages so great (such as saving in space, absence of smoke, power always ready to be switched on or off as required, etc.) that it would pay the mill-owner well to employ it. Besides, the price came down according to the quantity used, on the sliding scale, and in large mills using large quantities it would be much less than 1d. per unit.

He hoped that Mr. Earle would enlarge his paper as he had suggested, and publish it. He was certain it would prove most valuable to the promoters of other similar schemes.

Mr. Pooley.

Mr. POOLEY said: He would like to make a few remarks with reference to the question of dielectric strength and the Board of Trade regulations with regard to it. Experience had shown that, especially on high voltage, the Board of Trade regulation thickness is excessive. In proof of this he would draw attention to the smaller of two large specimens on the table; this sample was a 37/15 3-core cable built to Board of Trade regulations for 6,500 volts; therefore, it had 175 mils. of insulation on each conductor (making 350 mils. between conductors) and 175 mils. overall (making 350 mils. between each conductor and the lead sheath). A 6-feet sample of this cable had been bent round a drum only 9 inches in diameter, straightened out again three times, and generally ill-treated by being struck with sledge hammers, after which it was subjected to thirty thousand volts without failure. Another sample of the same cable, but without the ill-treatment test, could not be broken down with sixty thousand volts. He was quite satisfied that cable could be made for the same pressure, and to stand the necessary tests, having 100 mils. on each conductor and 100 mils. overall, making 200 mils. between live points; this would still give a very large factor of safety.

Coming to the question of the relative cost of the two cables. On a 0·15 3-core cable for 6,500 volts and of the Board of Trade thickness, the cost is £730 per mile. A cable with similar conductors, with the thinner insulation referred to, would cost £595 per mile, which meant that, by adhering to Board of Trade regulations, consumers were paying on this size of cable 22½ per cent. more than is necessary.

He would like to mention a case of a test he made a short while ago, which would show what very high dielectric strength could be obtained with modern insulation.

He had a 0·15 single cable covered only with 90 mils. of dielectric: this cable stood several applications of 60,000 volts, finally breaking down at about 55,000 volts. Of course, it would not be advisable to reduce the dielectric thickness at the expense of mechanical strength, but the ill-usage tests now specified, of which the one he had mentioned was a very severe example, might be relied upon to discover any weakness in that direction. The bending test referred to, and also

those mentioned by Mr. Fawcus, showed what a large margin of safety there was. He thought makers might generally be relied upon not to run risks in this direction. One disadvantage of the reduced distance between conductors would be the consequent increase of the electrostatic capacity. This, however, was not of much importance, so long as that of all the cores was kept equal, except at times when the cable was lightly loaded. Mr. Pooley.

Mr. Earle had said that exact information as to the heating of the cable did not appear to be available; this was true, but it had been deduced from actual tests made on rubber cables, that on a 0·15 cable 1,000 amperes per square inch would not raise the temperature more than 10° F. It had also to be considered that it was very rarely that a cable was fully loaded for any length of time. He did not think that there was any fear of damage being done by overheating at that current density.

The Board of Trade regulations with regard to laying these extra high-tension cables seemed to have been drawn up with an idea of making as thoroughly good a job as possible without sparing expense. At first sight it seemed rather strange to have an armoured cable laid solid in iron troughing, but an advantage of this method of laying was that the armouring, which was electrically connected to the iron troughing, made any fault which occurred distinctly a local one. In case of a blow-out, too, there would be none of the spluttering and burning that there would be if the lead were the only earth. In country districts, however, he thought a large saving might be made by laying cables with a specially good armouring such as "lock armour," a sample of which was on the table, direct in the ground, as a fault there would not cause much disturbance to traffic or danger to life, as it would in town streets. A saving for 0·15 cable laid direct in the ground with special armour over the same cable with ordinary armour laid solid, would be £265 per mile.

Mr. H. A. Earle, in reply (*communicated*): One of the most surprising features in the discussion which has taken place is the divergency of opinion that has been expressed, but I feel convinced that if those who have adversely criticised the future of the large power companies, give the matter fuller consideration, they would be inclined to modify their views. In my reply I may hope to induce them to entertain more favourable opinions, for I trust I shall be able to make several points clearer than it was possible to do in the permissible length of a paper. Mr. Earle.

There is one statement which has been made before the Parliamentary Committee, in connection with the Lancashire Power Bill, with regard to the cost of carrying coal *versus* the cost of transmitting energy electrically. It has no great bearing on the subject as a whole, for the problem, if considered commercially, becomes insignificant of itself, but I have given the figures, and Mr. Wordingham has replied. The statement, however, as it stands, is misleading, and the point requires further explanation. Taking his printed evidence, it is stated that when transmitting 1,000 k.w. 25 miles, with mains costing £1,800 per mile, and with a 25 per cent. load-factor, the interest charges alone

Mr. Earle. on the cables equal 0·49 pence per unit, and that the cost of carrying fuel equals 0·059 pence. On working out these figures I was surprised to find that the figure 0·49 represented 10 per cent. on the assumed cost of the cables. Mr. Wordingham has, however, corrected the error, and has explained that this should be divided into two items, namely, 5 per cent. for interest and 5 per cent. for depreciation. The question of sinking fund is not involved in this case. I cannot, however, agree to the amount of 5 per cent. for depreciation without further subdivision of the item, and taking the figures in my paper the items are as follows :—

4½	per cent.	Interest
2½	" "	Depreciation.
1½	" "	Repairs.
½	" "	Superintendence.
9	per cent.	

Again, for his comparison the cost of the mains are taken at £1,800 per mile, and the distance to which the power has to be transmitted at 25 miles; these are figures which do not put the problem fairly before us. I adhere to my figure of £1,000 per mile for the mains, and 10 miles as the probable maximum distance the power companies will arrange to transmit from their stations. I note that Mr. Wordingham has taken in his calculations a density in the mains of 600 amperes per square inch, which he probably considered desirable on account of the long distance he had assumed for transmission, but I consider this density too low for economical working, and the higher density is more suitable. Again, I asked Mr. Wordingham what weight of coal he had taken per kilowatt-hour, and he replied that the more he had taken the better for my case. To this I reply that the less he has taken the better for his, and from his figures we find the following :—

Cost of carriage :—

25	pence at 1d. per mile.
6	pence terminal charge.
12	pence cartage from station.
43	pence per ton.

1,000 k.w. with 25 per cent. load-factor equals 2,190,000 units per annum, and $\frac{2240}{43} \times {}^{\cdot}059 = 3{}^{\cdot}07$ lbs. of coal per unit.

Such a result is not obtained by any supply in the country. It can be attained with large plants on a six-hours full-load run; but the fuel consumption, taking coal at 10s. per ton at the station, if worked out from the published costs for 1900 for the following towns, is as below :—

Mr. Earle.

	Cost of Coal per Unit, as per the published returns.	Lbs. per Unit sold.	Or lbs. per Unit generated, say 20 per cent. less.
Manchester ...	0·44	8·2	6·56
Huddersfield ...	0·46	8·59	6·87
St. Helens ...	0·5	9·33	7·47
Liverpool ...	0·6	11·2	8·96
Bolton	0·77	14·37	11·5

I find that these figures, owing chiefly to traction loads and better load-factors, have been since reduced, and below I give the figures that have been sent me for 1901. Some of the figures were for units sold and some for units generated; the proportion of units sold to generated has been taken at 80 per cent.

	Price of Coal per ton delivered at the Station.	Cost per Unit.		Lbs. per Unit.	
		Generated.	Sold.	Generated.	Sold.
St. Helens ...	12s. 3d.	0·35	0·438	5·33	6·66
Liverpool ...	11s. 0d.	0·399	0·499	6·8	8·5
Central London...	...	...	...	7·0	...
Bolton	8s. 4d.	0·4	0·5	9·0	11·25

We therefore see that Mr. Wordingham's weight of fuel has to be multiplied by two or three for a large town, and it would have to be increased four times for one by no means small. Whatever the fuel consumption at the generating stations of the large power companies may be, the real point at issue is, the consumption at the smaller centres to which power is to be transmitted, and this, based upon the results which have been obtained, cannot be taken at less than 10 lbs. per k.w.

Basing the case upon the figures I have given, and assuming that 2,190,000 units per annum are transmitted 10 miles, we find :—

10 miles of mains @ £1,000 per mile = £10,000 @ 9% = £900.
The total lost units = 414 for 10 miles per day × 365
days = per annum 151,110 units.
Cost of generation @ 0·4d. per unit = cost lost units £251 17s. 0d.
Total cost of transmission ... ... £1,151 17s. 0d.
or 0·126 pence per unit.

Mr. Earle. Taking the fuel consumption @ 10 lbs. per unit,

$$\frac{2,190,000 \times 10}{2240} = 9,777 \text{ tons.}$$

Cost of carriage on coal (10 miles) @ 28d. per ton = £1,140 13s. od. or 0·125 pence per unit.

Showing the cost to be practically identical.

There is one other statement made by Mr. Wordingham which requires a reply. He quotes a figure which I gave of 0·2d. per unit, and compares this with a figure of his own of 0·025d. per unit, concluding from his comparison that electrical transmission cost eight times the carriage of coal. In order to ascertain how the 0·025d. per unit (cost of carrying coal) is arrived at—for it is not my figure—I have again assumed energy transmitted 10 miles, carriage and terminal charges costing as per Mr. Wordingham's figures 28 pence per ton, and based upon his figure of 0·025 pence per unit, I find that this represents a fuel comsumption of 2 lbs. per unit. This last figure he has since informed me is based upon the assumption that gas engines are used. With regard to my figure of 0·2 pence per unit, I have stated exactly what this is, and it is quite evident that if any undertaker or customer situated 10 miles away can generate electricity at a price not exceeding 0·2 of a penny above that at which the large power companies can generate it, he will be in a position to consider whether he should spend his own money. It, however, appears to me that the advantage to the public will be such that they will be able to obtain power from the company at a rate considerably less than that at which municipal authorities and lighting companies are able or willing to supply their customers.

Respecting Mr. Wordingham's remarks on the term "Supply in bulk," which he considers misleading, as it tends to intimate that the power companies can work more cheaply on account of the responsibility of distribution being shifted to other hands, I cannot agree with him if he contends that costs are not reduced by generating on a large scale, and that small towns cannot be more cheaply supplied from one central station than if each had its own centre; for we have only to look at the published returns to convince ourselves to the contrary. He also considers that, owing to their number, if the small towns are supplied, the sub-station charges will be considerably increased; but this is not necessarily the case. The small towns must build their own distributing centre, and lay their own mains, and arrangements can be made by which the machinery for conversion is located in the same building and looked after by one staff, thereby tending to reduce costs rather than to increase them. The same remark also applies to the tramway companies, who will do their own distribution and supply their own boosters. Mr. Wordingham's comparison of the relative merits of water-power abroad, *versus* coal at home, is one with which I quite agree, but I have not endeavoured to compare them in my paper. I have considered the English power schemes upon their own merits, and practically the whole of my paper is given up to the consideration of their economical feasibility.

Mr. Earle.

The figures given by Mr. Mountain for the output at Huddersfield are later than the last published returns, and the large yearly increases show the continual development of electrical supply, and are a good augury for the future of the power companies. Mr. Mountain's sub-division of the inhabitants of the district in no way affect their number. He also considers that I have not allowed for sufficient spare plant in my estimates, but as I have included machinery for 120,000 H.P. with a maximum demand of 100,000 H.P. this seems to me ample, whether the generators be of two types or one. I have also included 20 per cent. for spare plant at the sub-stations.

With regard to the estimate of the horse-power in use in the Yorkshire Power Companies area, the figure given in parliamentary evidence is not of much moment, and was only quoted in this paper to demonstrate that even 5 per cent. of the estimated figure would fully load up the four power stations without taking any account whatever of the supply for tramways, light railways, aud lighting.

With regard to the figure I have given for coal, viz., 0·128d. per unit, Mr. Clirehugh suggests that this is rather low, as he points out that it represents 3 lbs. per unit at 7s. per ton. In my calculations I have taken 6 lbs. per unit generated with coal at 4s. per ton at the pit, at which price it can be obtained. It is interesting to note the different figures taken, and we find that Mr. Mountain, to prove the case of the Local Authority and the inability of the Power Company to supply mill-owners, takes 5 lbs. per unit and slack at 3s. per ton. If, however, he were to work out the cost to the mill-owner per unit generated, he would find that there is much to add to the 0·06d., which he gives as the cost of carriage of coal, and from which he draws his comparison. I should certainly advise Dr. Panton and Mr. Mountain carefully to consider what Mr. Highfield has told us, for here we find the St. Helen's Corporation carting coal from the colliery and sending it back to the colliery in the form of electrical energy and saving them four-fifths of their previous expenditure.

The load-factor taken of 25 per cent. is another point upon which some have agreed, while others have not. Mr. Clirehugh, Mr. Fawcus, Mr. Highfield, and Mr. Sturgeon have accepted it as reasonable, while Dr. Panton and Mr. Taite take the opposite view. There are, however, towns with a load-factor of over 20 per cent., while many nearly reach that figure, and it is not too much to expect that with a cheap supply for motive-power the figure I have named will be reached. Exception has been taken to the load-factor of 50 per cent. which I have assumed for tramways and light railways; this is no doubt somewhat high in comparison with present-day results, but it occurred to me that as these undertakings would be charged in accordance with their load-factor, which is not the present case with municipal tramways, it would be well worth their while to install floating batteries and improve their factor. This problem has, I understand, been worked out and shows the advantage I have indicated. Mr. Sturgeon's forecast of the load-factor, though based upon considerable experience, is, perhaps, somewhat too sanguine, but based upon the results at Trafford Park it is not impossible. The power companies will have means at

Mr. Earle. their disposal for improving their load-factor, namely, by running their night load from one station, and during the day by distributing it in the most economical manner, for the trunk mains can be conveniently linked through the outlying sub-stations, and the load distributed as desired.

Mr. Shaw congratulates me upon having become a disciple to multiphase current, and intimates that I was antagonistic to it a year ago. He is, however, speaking from memory and it has betrayed him. With regard to this question, Prof. Silvanus Thompson, during the discussion (March, 1901) on Mr. Eborall's paper relative to three-phase and direct current systems, said, "I know it is an old question and a sore question. It is a question which we have discussed here, and a question which our Manchester friends have discussed in their own way. They have come to a somewhat surprising conclusion, or perhaps a conclusion not surprising at all if they have got such extraordinary ideas as to suppose that continuous-current motors are either lighter, more regular in speed, more efficient or more cheaply made than three-phase machines. If they put their heads in the sand and choose to start an argument by the assumption that these things are so, then of course they will come to the conclusion that it is better to work with continuous current; but if their premises are unsound, the arguments are absolutely baseless." I wish to take this opportunity of answering Prof. Thompson. In the first place there can be no doubt whose head is in the sand, for he received a copy of my paper read in November, 1900, and he has not even done me the justice to read it carefully, for he has not quoted me correctly, and at the same time has misrepresented me. In the first place, I did not say that direct-current motors were lighter than polyphase. I said, "Respecting the weights of the two types of motors, the polyphase type, with squirrel-cage rotor, is considerably lighter, and some 5 per cent. cheaper, and that three-phase motors of 50 to 100 H.P. with wound rotors weighed about the same as direct-current motors, and that for large motors quotations from abroad showed on the basis of our own selling price 10 per cent. in favour of direct-current motors." With regard to efficiency, I do not agree with him, for direct-current motors are more efficient. I gave the figures, and adhere to them. With regard to regularity of speed, I would refer him to what I said. In further reply to Mr. Shaw, my statement of eighteen months ago was, "The polyphase system is at the present time the most satisfactory solution of long-distance transmission, and will be utilised more and more to transmit large powers into the centre of towns, and to cope with the many difficulties which present themselves."

As to Mr. Fawcus's and Mr. Pooley's remarks respecting the cables, the results of the tests which have been made are most valuable, and any reduction in insulation would tend considerably to reduce the price of £1,000 per mile laid; but with regard to the thickness of insulation fixed by the Board of Trade, it appears to me that the question of the mechanical strength of the covering must be carefully considered, as well as its insulating properties, for should a power company have laid cables representing a sum of some three-quarters of a million, it would be

disastrous to the enterprise if trouble should be afterwards experienced. Mr. Earle. There is a possibility, however, that in some of the across-country mains they can with advantage as regards expenditure be laid direct in the ground without cast-iron troughing, or bitumen; this would effect a large saving, probably of some 15 per cent., and is well worth consideration.

Dr. Panton has referred to the Berlin undertakings, but he does not give particulars of the load-factor, nor of the proportionate amount of energy supplied for lighting and power. Their custom is, without doubt, chiefly one for lighting, as their high rate of charge indicates. Dr. Panton asks what is the "bed rock" price at which customers can be supplied: this very largely depends upon the customer and his load-factor, and in the sliding scale I hold the distance of the customer from the generating station should be considered, for a large works built alongside the generating station would entail no expenditure for mains or conversion. I consider, however, that the power company could with profit supply a works having 30 per cent. load-factor at a price of, say, 0·9 of a penny per unit, whereas an electrolytic works built alongside the generating station could obtain current at about 0·35d., or possibly a little less.

Those who have joined in the discussion have referred to the question of gas for firing the boilers or for driving gas-engines, to overhead conductors, thinner insulation for the underground cables, and power supplied to electrolytic works at a high load-factor. It has been suggested that I might have considered these matters, and have pointed out their advantages. It is perhaps hardly necessary to say that these and many other matters passed through my mind while I was preparing my paper; even now it has been called a dream, and if I had embodied all these items it would certainly have been a nightmare. In order that the financial consideration of the matter might stand upon as sound a basis as possible, I decided to adhere to the Board of Trade precedents as regards underground cables and to omit overhead cables, and to let gas producers, gas-engines, and electrolytic works come as a bonne-bouche at a later period.

DUBLIN LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

Delivered December 19, 1901.

By Professor W. F. BARRETT, F.R.S.

It seems to me that one of the most useful functions of a local section is to aim at doing what a local museum should do, viz., strive to collect and preserve and present to the public all that is of special local interest. We should aim at bringing before the public the electrical investigations or works accomplished in our locality, and further that we should keep in remembrance all local men who, in the past, have by their writings or discoveries or inventions contributed to the upbuilding of the science of electricity. I may return to this later on, but the point I wish to emphasise now is the importance of our encouraging and making known original research or inventive skill in our own locality. For the Institution of Electrical Engineers affords a striking illustration of the union of practical electricians and electrical engineers with the students of pure science. This is as it ought to be; for the progress of modern civilisation depends on the co-operation of those who are enlarging the boundaries of our knowledge with those who apply that knowledge to the material needs and the comforts and conveniences of our daily life. It is obvious—though our statesmen and mankind generally are slow to recognise the fact—that the wonderful and varied applications of electricity which have signalised the last fifty years are the outcome of, and dependent upon, scientific research. If a society or a nation does not encourage and honour such research, that society or nation is sure to fall into the background, and eventually be overthrown by those who are wiser and more far-seeing. When we go abroad (as Mr. Sheardown described at our last meeting) and see the magnificent institutions which exist, especially in Germany, Switzerland, and America, founded, equipped, and maintained by their respective Governments for the cultivation and diffusion of scientific knowledge, we are not surprised at the industrial and commercial progress those nations have made. Not long ago Lord Rosebery, in opening a technical college in England, stated that a friend of his went to Germany specially to investigate what was being done there, and, in Lord Rosebery's words, he came back "absolutely *appalled* by the progress made in the last twenty years by the Germans in technical and commercial education as compared with what was going on in England," and he urged, what has so often been urged by our leading scientific men, that a responsible council should be formed by our Government to advise them on all matters respecting the progress of science and industry. We do not, however, need such a council to tell us, what any one can ascertain for himself, that the total amount of moral and material support given by the British nation, the

wealthiest in the world, towards the advancement of science and towards *higher* scientific and technical education in England is absolutely insignificant compared with what is given in Germany or in the United States.

Bad as the state of things is in England it is still worse in Ireland, for the total amount of funds annually provided by the Government for higher scientific and technical education in all Ireland is less than the individual income of many a professional man. The reason for this state of things is not far to seek. As a nation we have until lately adopted the principle of *laisser faire*, the non-interference of Government in educational or other matters, which the individual is expected to provide for himself. But we have been compelled to abandon that attitude as regards primary education, for primary education is now provided by the State, and we shall be compelled to abandon it as regards at least one part of secondary education—that part involving the use of special appliances and costly equipment, which is beyond the means of an individual teacher or an unendowed college to provide. And it is because higher scientific technical training involves the use of well-equipped laboratories and ample space, in addition to skilled and enthusiastic teachers, that this branch of secondary education must be provided for by the municipality or the State. Hitherto this fact has hardly been recognised in our own country; for the educational training of our rulers has been mostly at public schools and colleges where science is almost unknown, and hence the importance of this subject is ignored.

No doubt the new Department which the Government have founded in Ireland, and of which I am an officer, realises the value of higher scientific education and will endeavour to remedy the evils of the past. But Governments and Government Departments are powerless unless they have an enlighted public opinion to sustain them; and hence it is the duty of every good citizen of this country to inform his mind and exercise his judgment upon this great question; and when he has done so let him strive to assist those who are administering a trust that may be of the utmost importance in the future in our land.

And here let me say, as one who for over twenty-five years has been engaged in scientific teaching, and daily striving to wake the public out of their apathy on this question, that in my opinion the success of technical education, the benefit that it will confer on our country, will largely depend upon its working from above downwards and not from below upwards. I mean by that, that the establishment of evening scientific and technical schools throughout the country for the wage-paid classes, though a useful work, will not be of national value unless employers of labour, professional men, and directors of large industrial companies, and capitalists, first obtain a proper collegiate instruction in science and the applications of science to industrial pursuits. The foundation for scientific and technical training is a good general education at school, and it is only those who have had such education that can take useful advantage of scientific teaching. Hence, in my opinion, we in Ireland should do what the Germans have done—viz., begin at the top of the scale and work downwards. In this opinion I am supported by one of the ablest Ministers in the present

Government—Mr. Hanbury, the President of the Board of Agriculture—who only a few days ago, in an address on Technical Education which he gave at Derby, stated "That he believed that the advantage which the United States and Germany had over our own country was *not* in the technical education of their working classes, but in the scientific and technical education of the great leaders of their commerce and industry;" and he added, "England was far behind Germany and America in that respect, for a technical and commercial education must spread *from the top to the bottom.* Education must be instilled into our leading commercial men even up to the Universities themselves. This is the reason," Mr. Hanbury further remarked, "that in their technical schools in Great Britain they did not find those day scholars and advanced students which ought to be flocking into them." Now if this be true, and it certainly is true of Great Britain, how much more is it true of Ireland, which has hitherto suffered so much from the want of general education among the masses of the people.

Flourishing industries used to exist in our midst which have now almost disappeared, unable to stand against the competition of the world. No doubt economic causes have been at work in this sad decline, but is not a contributory cause to be found in the want of that superior commercial and technical knowledge which can alone create skilled leaders and captains of industry. Where you find such men, you also find a flourishing industry, even in this country. Is there any valid reason why Dublin should not be as famous for its *electrical engineering workshops* as Sir Howard Grubb and his father have made it famous for its astronomical works, or Messrs. Guinness for its porter? One valid reason, I believe, does exist, and it is one which ought not to exist. It is this: not a single chair of electrical engineering, nor even of mechanical engineering—and the two are inseparable—is to be found in the whole of Ireland. I trust our Parliamentary representatives will use their influence speedily to remedy this grave defect in the higher scientific education of this country, a want that in season and out of season I have been drawing attention to for the last fifteen years. I am well aware that holders of other chairs in our existing colleges do their best to meet this pressing need. But they have not the time nor the equipment nor the accommodation necessary for adequate instruction in these vast and important subjects. In England, and still more in the United States, private benefaction for educational purposes is much more common than in Ireland. Immense sums have been given by wealthy persons for higher scientific instruction in America, and the magnificent electrical engineering laboratory in Owens College, Manchester, is the generous gift of the Hopkinsons. Would that some of our wealthy men here would follow that example! Some persons are under the impression that large funds are at the disposal of this College; this is the very reverse of the truth. The annual sum voted by Parliament for this, the only college in Ireland for scientific and higher technical training, remains at the same pitifully small and inadequate figure which was given at the outset more than thirty years ago, though the number of its students have increased fivefold and the cost of practical laboratory instruction has been added to every chair.

I must apologise for referring to this matter, but I do so in order to show the need of more enlightened public opinion on scientific questions and their bearing on the industrial development of our country.

Before I pass from this subject let me say one word on behalf of that much-abused body, the Corporation of Dublin. To them belong the credit of being the first municipal body in Ireland to open and maintain a technical school for both sexes, though they had not the Imperial funds at their disposal which the Technical Instruction Act gave to municipalities in Great Britain. The technical schools in Kevin Street, where one thousand evening students are enrolled, is a most admirable and efficient institution, and I am glad that I see before me several of its students in the electrical engineering classes which are so ably held there by my colleague, Mr. W. Brown. In connection with these technical schools we ought not to forget how much they owe to their first principal, Mr. W. V. Dixon, and also to the self-sacrificing devotion of Mr. Arnold Graves, the pioneer of technical schools in Ireland.

Passing from this topic, on which I have dwelt longer than I intended, let me return to that subject which interests us in a special degree. As mankind have in the progress of the race passed through a "Stone Age," a "Bronze Age," and an "Iron Age," we are certainly in the midst of the "Age of Electricity." It has become our great carrier, whether of news, or speech, or energy, or matter. Its applications meet us everywhere, even in the wilds of Siberia, for the first business in a new settlement, whether in the backwoods of America or Russia, appears to be an electric light installation.

It seems almost incredible that the discovery of current electricity was only made a century ago; but so it is! And how remote from any idea of its commercial use, how entirely the result of pure scientific research that discovery was! The Italian savant Galvani's well-known experiments with frogs, and Volta's copper-zinc couple are about as far removed from our electric lighting or electric traction as anything can be. And so it was the work of the illustrious Faraday—I fear, though his name was Michael, we can't claim him as an Irishman—Faraday's imperishable researches in electricity—conducted in what was originally an underground kitchen in Albemarle Street, London—have, as we all know, led directly to all the modern developments of electricity; without Faraday's discovery of magneto-electric induction we should have had no telephones, no dynamos, no electric lighting, nor electric traction.

It has been my privilege to know many eminent scientific men from the time of Wheatstone onwards, but none reached the simplicity and beauty of character nor the marvellous insight into nature possessed by this famous son of a journeyman blacksmith, Michael Faraday:—

> "His life was gentle and the elements so mixed in him,
> That Nature might stand up and say to all the world,
> This was a man."

I saw him almost daily during the last few years of his life, and I recall, as if it were yesterday, the animation and delight with which he gave

me a small rod of iron, the size of a cedar pencil, which had that day been melted by a Wilde's machine, the first powerful current obtained through his discovery of magneto-electricity.

[Portraits of Galvani, Volta, and Faraday, and of their respective laboratories were here thrown on the screen.]

I have referred to Faraday and the beginnings of modern electrical development to illustrate how scientific progress depends on original research in the laboratory, and also to point out that it is by *exceptional* men like Faraday, Clerk Maxwell, Lord Kelvin, Helmholtz, and others that higher levels are reached by the human race as a whole. If there had been time I should like to have shown the large share in this intellectual and scientific progress which is due to eminent Irishmen, including in this term men of Irish ancestry. But this I cannot do to-night, and will only mention one or two facts in this connection. That remarkable man, the Hon. Robert Boyle, who laid the foundation of our modern methods of experimental research, and was one of the founders of the Royal Society of London, was born at Lismore Castle in the county Waterford in 1627. Boyle's experiments on electricity were among the first ever published; his industry was amazing, and his open-minded and fearless pursuit of truth for its own sake is an example to all generations; he did not fear being laughed at in his quest for natural knowledge, and in this he teaches a salutary lesson to those who fear to go outside the fashionable materialistic philosophy of their day.

[Reference was then made to the work of Dr. Callan at Maynooth in the past generation, and to the excellent researches on the theory of contact electricity made by Mr. J. Brown, of Belfast, in the present generation. Lantern slides were shown of various pieces of electrical apparatus designed by Mr. Brown. Professor Barrett then exhibited the phenomena of the anomalous contraction of iron in heating and expansion on cooling at the critical temperature, and showed these experiments, and also his discovery of recalescence on a large scale. He then continued] :—

We live in a country the most important industry of which is *agriculture*, and it would be an appropriate and valuable undertaking if some members of our section were to devote their time to the application of electricity to *agriculture*. On the Continent and in America agricultural operations on a large scale are often carried out by electric motors; the stores of water-power we possess might in certain districts be utilised for this purpose. The valuable statistics of the available water-power in Ireland, given in Sir Robert Kane's *Industrial Resources of Ireland*, need to be revised and brought down to date.[1] Why should not electro-chemical industries be established in this country wherever considerable water-power is available, as well as in the Highlands of Scotland or of Norway?

If this be impracticable, there are other applications of electricity to agriculture. All electricians engaged in line testing know how much the *resistance of the earth* varies in different places and in different seasons, and what an important element this is in dealing with the

[1] See on this subject an admirable paper by Mr. Tatlow read at the Dublin Section since this address was delivered.

return current; the electrolytic action set up by heavy currents and the damage done to the rails or service pipes in part depending on the nature of this resistance. Dry earth is almost an insulator, wet earth is a very fair conductor; clay with 6 per cent. moisture averages about 50 ohms per cubic yard, certain soils when saturated with salt water fall as low as 1 ohm per cubic yard. So that the resistance of the earth ranges from 1 ohm to about a megohm per cubic yard.

Now this variation of resistance can be employed to ascertain the amount of moisture in a given soil. As different plants require different amounts of moisture for their healthy growth, and as the amount of water required varies according to the stage of growth of the plant, a knowledge of the humidity of the soil is a very important factor in agricultural and climatological investigation. I am indebted to my friend, Mr. J. R. Kilroe, of the Irish Geological Survey, for drawing my attention to the fact that the United States Department of Agriculture have for some time past employed with great success electrical methods for determining the moisture in different soils. In the *Year Book of Agriculture*, issued by the United States Government for 1898, it is stated that sixteen stations have been equipped with electrical measuring instruments for determining the humidity of the soil in different places, and in the same place at different seasons. Pairs of carbon electrodes are buried at different depths in the ground, and to avoid their polarisation an alternating current is employed; to compensate for changes of resistance due to temperature alone, what is called a "temperature cell" is included in the circuit. In a given soil the resistance varies in some inverse ratio to the water content in the soil, and a simple reference table enables the observer at once to deduce the quantity of water in the soil from the resistance, the standardisation of the apparatus for the particular locality having first been made. The secretary of the United States Department of Agriculture states that the result of these electrical records has proved of great value in soil investigation, and is likely to be of considerable practical and commercial importance to farmers. One great advantage of this method being that as the electrodes remain undisturbed—merely a lead-covered cable appearing above the ground—the fields can thus be cultivated and cropped as usual without any interruption of farming operations—in fact the wires may be laid to a central recording station.

It is obvious that a very simple apparatus might be devised which would enable any farmer to make use of this method. For instance, the resistance might be found by a telephone; and if the soil resistance is balanced against a known resistance, all the farmer would have to do would be to shift a handle till he heard no sound in the telephone, and then read off directly, on a calibrated scale, the amount of water per cubic foot in the soil.

A similar method can be used for finding the relative amount of *salts* in any soil. This has successfully been tried by the United States Department of Agriculture. A sample of the soil at a given depth is taken, dried, and then mixed with a known quantity of water; it is now packed in an ebonite trough with electrodes at a definite distance, an alternating current transmitted and the resistance measured, the

temperature being noted. An equal volume of this soil is then mixed with a known quantity of the *salt*, plus the same water, and the resistance again found. In this way, as the added salt lowers the resistance, a very sensitive and accurate measure is made of the percentage of salt present. When the salts in a soil are of the same kind, this method is found very valuable, but of course it is inapplicable where a great mixture of salts occurs in the soil. As these electrodes can be placed by means of small drill holes at any depth below the surface, it is obvious that we have here a method of making an underground survey of the soil at different levels—a matter of very great importance when alkali works exist in salt-bearing regions.

The temperature variations of the surface soil and the conditions which favour warmth, are also found by noting the varying electrical resistance of a buried coil of wire; these methods have all been recently worked out for agriculturists by Mr. Lyman Briggs, the physicist to the U.S. Department of Agriculture.

Another application of this method of measuring the resistance of the earth in different localities has occurred to me, and, as soon as time permits, I will endeavour to ascertain if it be practicable. This is the location of underground water for the purpose of comparatively shallow or surface wells. The location of large water supplies, and deep artesian wells, we must leave to the geologist. But in certain districts where rock fissures exist below the surface, or a narrow bed of sand or gravel, or other permeable stratum of small width occurs beneath an impermeable layer of clay, water is usually found traversing these underground channels, and its exact position is difficult to locate without numerous and expensive borings, or having resort to the very unscientific, but nevertheless practically useful, water-finder or "dowser," as he is called in the South of England. It seems to me we might all become "dowsers" if we drove metallic rods, armed with a sharp spike, deeply into the ground, and tested the conductivity of the soil intervening between different pairs of electrodes, all at the same depth and the same distance apart. We certainly ought to obtain considerably greater conductivity in the direction in which the permeable water-bearing stratum lay, and thus could ascertain its approximate position and depth below the surface. If this be so, its immense practical importance is obvious to those who have had the misfortune to sink numerous wells without getting any water.

Again, might it not be possible to utilise a knowledge of the different conductivity of the ground in metalliferous regions? Underground electrodes might lead us to ascertain the direction of profitable veins of ore from the greater conductivity of the metallic lodes.[1]

Why should not we adopt similar methods as regards agriculture in this country? Let us hope the attention of the Department of Agriculture in our own country will be directed to this matter.

[1] Since the above was written, I have been informed that an American company, called the "Electro-Geodetic Mineral Finder," has been formed to exploit an instrument which carries the above idea into practice. The president of a mining company in California states that he has used this method with remarkable success: in a few days "it has done more than a year's prospecting could have done."

There is another application of electricity to agriculture which, if it be established, is even more important, though at present the statements made need further confirmation. I refer to the effect of electricity on the growth of plants, on the germination of seeds, and on the general health of a plant. I propose to bring before this section at some future time, if all be well, the results of my inquiries on this important question. At present I will only make a brief reference to this subject.

One of the most common popular delusions is to ascribe everything that cannot readily be explained, or which seems mysterious, to *electricity*. At the present day, among the uneducated, electricity has taken the place of mumbo-jumbo, a kind of god behind the scenes, whose wayward freaks account for everything that happens out of the common. Whether it be a boiler explosion, or table-turning, or water-finding, it is sure to be *electricity*. Every scientific man, however, knows that in 99/100ths of these cases, whatever be the explanation, we are sure it is *not* due to the thing we call electricity. Hence a very natural incredulity exists among all electricians when they hear, as we do from time to time, of wonderful effects being produced on the growth of plants (generally potatoes) and their power of resisting disease, produced by the electrification of the air or the soil. Though reports of this kind go back more than 150 years, I paid small attention to them until an old student of mine, an able physicist, Dr. Cook (lecturer on physics at the Merchant Venturers College, Bristol), read a paper on the subject at the British Association Meeting in 1898, and sent me a report of his numerous and carefully conducted experiments. These experiments undoubtedly appear to establish the fact that the germination of seeds and the growth of plants *can* be accelerated by proper electrification of the air or soil around them.

Apparently unaware of Dr. Cook's investigation, the late President of the Institution of Electrical Engineers, Professor Perry, in an article in *Nature* last year,[1] drew attention to the researches of an eminent German physician, Dr. Schliep, on the effect of atmospheric electricity on animal and vegetable life. As regards human beings Dr. Schliep found that negative electrification of the atmosphere was usually accompanied by unhealthy symptoms; fatigue, lassitude, loss of tone, weariness without obvious cause—and even certain forms of disease were found prevalent with negative electrification—which in general was unfavourable to healthy animal tissue change. According to Dr. Schliep, the decomposition of meat and bad smells from drains were another symptom of negative electrification. On plant life what injuriously affects us seems favourably to affect them; negative electrification promoted tissue change in vegetation and promoted the growth of plants. Professor Perry appears to think these conclusions at which Dr. Schliep has arrived are worthy of credence after a personal interview with the doctor. But neither Dr. Schliep nor Professor Perry appear to be aware of the body of literature there is on the effect of electricity on vegetation—a literature which includes reports of experiments by some of the very ablest English and Continental men of science during the

[1] See *Nature*, March 15, 1900, p. 471.

last 150 years. The results of these experiments are singularly conflicting, but a closer scrutiny reveals the fact that those experimenters whom we must regard as most trustworthy, such as the Abbé Nollet in 1750, M. Bertholon in 1783, Sir Humphrey Davy in 1810, M. Ed. Becquerel in 1830, and in more recent times, M. Paulin, director of the Agricultural College at Beauvais, M. Barrat, M. Spechnew in Russia, Professor Lemström of Helsingfors, and M. E. Berthelot, are all agreed on the remarkable results which, under certain conditions, can be attained by the electrification of the air or soil around plants.[1] A common method of experiment, going back over a century, but published as new every few years, is to erect a series of lightning conductors on insulated supports, and connect the lower terminals with a series of parallel wires traversing the soil or air around the crops. Comparative experiments on various crops grown in exactly similar ground, with and without the wires, were recently made by Dr. Cook in Bristol, and the results were striking enough: those with wires yielding earlier and larger crops; potatoes profiting the most.

Here, in Ireland, Mr. Martin O'Sullivan, the school teacher at Athea, in co. Limerick, has tried similar experiments in entire ignorance of any work that had been done elsewhere, and though Mr. O'Sullivan's notions of electricity and the way it affects his crops are very crude, yet some of his results seem to have been carefully arrived at, and are in accordance with exactly similar experiments in France, Germany, Russia, Finland, and England. Mr. O'Sullivan,—like M. Paulin in France, M. Spechnew in Russia, and Dr. Cook in England,—made comparative experiments on the yield of potatoes planted in exactly similar plots of ground; in one case the plots had wires traversing them, the wires being connected to a series of vertical metallic conductors, supported by upright stakes some 7 feet high, whereas the adjoining plots had no wires nor stakes. The county surveyor of Limerick, Mr. J. Horan, in 1899, tested the result, and found that the yield within the protected, or wired, area was surprisingly larger than within the unprotected area. This result was confirmed in the present year by one of my students, Mr. M'Lurg, who visited the place and tested the results of another year's crop. M. Paulin at Beauvais, who used a vertical conductor some 25 feet high, found the yield of potatoes nearly a third greater in the protected than in the unprotected area,—91 kilos. to 63 kilos.

A *primâ-facie* case thus appears to be made out, and I am glad to know that comparative experiments of a similar character have recently been made here in Dublin under competent supervision. But a trained physicist, as well as an agriculturist or botanist, must take part in these experiments, or the conclusions will be open to doubt. We ought to remember Sir John Herschel's remarks in his discourse on *Natural Philosophy*, that "the man of science should hope all things not impossible, believe all things not improbable."

[1] Professor Lemström states, in a paper read before the British Association (see B.A. Report for 1898, p. 808), that extensive experiments he made in 1897 showed that electrification increased the yield of many crops and fruits from 40 to 75 per cent.; he thinks the result may be due to the formation of nitric oxides or ozone, or the more rapid ascent of juices in the capillaries of plants caused by electrification.

ORIGINAL COMMUNICATIONS.

A GENERAL FORMULA FOR REGULAR ARMATURE WINDINGS.

By David Robertson, B.Sc., Associate.

Explanation of Terms.—When the winding of an armature is traced out, the various conductors and end connectors are taken in a definite order, and it will generally be found after performing a certain number of connections that we commence a new series identical with the first, and that this series is repeated over and over again a complete number of times to make the whole winding. Such a winding is a *regular winding*, and the series of connections which is repeated over and over again will be called a *cycle of connections*.

A winding is *re-entrant* if it come back to the starting point and is then complete. An armature may consist of one, two, or more windings, each re-entrant on itself, and each independent of the others. It may therefore be *singly, doubly, triply, &c., re-entrant*.[1]

An armature with re-entrant windings is often called a *closed-coil armature*.

Each cycle of connections is made up of one or more contiguous *spirals*, or *sets of contiguous spirals*, and each spiral consists of a conductor going down from the front end, one coming up from the back, and the necessary end connectors.

One set of spirals will thus have two *groups of conductors*, one group in which the current goes down, and another in which it comes up. *Down* and *up* are employed with the meanings "from the commutator end" and "to the commutator end," respectively. The commutator end is termed the *front end*, and the other the *back*. If there is no commutator at all, or a commutator at each end, then we may call either end the front, and the other the back.

In most cases a cycle has only one set of spirals, or two groups of conductors. This would be a *2-group cycle*. In other cases there may be two or more sets of spirals in each cycle, giving a *4-group*, or a *multi-group cycle*.

The number of conductors in each group is in general the same as the number of spirals in a set. In large machines there is often only one spiral in a set, and consequently only one conductor in the "group." In such a case, the term "conductor" might be substituted, but it is convenient to include this special case in the general term "group," so

[1] A few writers use the term "re-entrant" in another sense. For instance, Sheldon and Mason, in their *Dynamo Electric Machinery* (London: Crosby, Lockwood & Co., 1901, p. 46), take the re-entrancy as being the number of times we must go round the armature in tracing out the whole winding.

as to allow one term to be applied to all cases, and thus make the statements perfectly general.

A *group* thus consists of the one, two, three, or more conductors close together on the armature, which are taken altogether as a unit in dealing with the numerical properties of the winding, and the whole group is to have one distinctive number.

In going from one group of conductors to another through the end connectors we pass over a certain number of groups. This number, including the one we go to, but not the one we leave, is the *pitch* of the connectors. The *front pitch* is the pitch at the front end, and the *back pitch* that at the back. These are often different, and there may be more than one of each in a cycle. When the group contains more than one conductor, it is to be understood that the several conductors in the two groups united by the back pitch are to be joined in series to form a coil, and the two ends of this coil are to come out at the front, and are to be treated as the front ends of their respective groups.

The part of the winding included between one segment of the commutator and the next in the order of winding, not necessarily an adjacent one, will be called a *section*.[1] The number of sections is thus generally the same as the number of commutator segments. In alternators, which have no commutator, this name is often applied to that part of the winding which is made up as one coil. In continuous current machines the sections are usually all alike, and as a general rule a commutator segment comes in at the end of each separate cycle.

In what follows it will be supposed that we are dealing with closed-coil commutating machines except when the contrary is expressed.

The *pole pitch* is the distance from the centre line of one pole to that of the next. It may be expressed in terms of the average circumferential space occupied by one group of conductors by taking it as the total number of groups divided by the number of poles. This unit will be referred to as the *group-space*.

The *pole span* is the actual part of the pole pitch subtended by the poles, and it may be expressed in a similar way.

In going from one section to another through the winding, we pass a certain distance round the armature. This, which may be expressed in terms of the average group-space, is the *travel*.

The travel consists of two parts: first there is a motion from pole to pole equal to the pole pitch or a multiple of it, and then there is a motion across the pole pitch. The latter is the *creep*. The creep for one section is thus the difference of the distances of corresponding groups in two consecutive (in the order of winding) sections from the centre lines of their respective poles.

[1] S. P. Thompson, in his *Dynamo Electric Machinery*, defines this as an "element" when dealing with this subject, and applies the name "section" to what is here called a "group"; but as a general rule the term "section" is used with the meaning here given to it, even in the work referred to.

Symbols.—The following symbols will be used :—

c = Number of circuits in parallel.
G = Number of conductors or groups of conductors, each of which is treated as a unit, and has a distinctive number.
g = Number of conductors in each group.
p = Number of poles.
r = Number of pitches, and of groups, in a cycle.
S = Number of sections.
s = Number of commutator segments.
t = Total travel for one re-entrance, expressed in revolutions.
u = Number of circuits in each winding.
v = Number of groups in each winding.
w = Number of independent windings = Number of re-entrances.
$\bar{y}$ = Average pitch of connectors.
y_1, &c. = Pitches of connectors.
y_f, y_b = Front and back pitches respectively.
Z = Number of active conductors.

The other letters stand for indefinite integers, whose limitations are explained in the text.

Preliminary Conditions.—A few conditions can be written down at once. For instance, c must be an even integer, for there are two paths from any point in a closed coil winding. Here, as throughout this paper, 0 is included among the even integers, and indeed among the multiples of any number.

Every cycle has to start in exactly the same way. Hence in each cycle the current has to come up as many times as it goes down, and consequently r must be an even number.

In order that each winding may contain exactly a whole number of cycles, and that all the windings may be alike, G must be a multiple of rw.

There will always be as many N poles as S poles. Hence p will be even.

The number of commutator segments will either be equal to the number of sections, or some multiple of it, generally the former.

There is no use of considering values of $\bar{y}$, y_1, y_2, &c., greater than $\frac{1}{2}$G, because any such value can be equally well expressed by a number less than $\frac{1}{2}$G with the opposite sign.

Condition of Re-entrancy.—The first condition to be fulfilled by a proposed winding is that it should re-enter upon itself. If when a re-entrance takes place, an aliquot part of all the groups has been taken up, there will be as many re-entrances as the whole number contains that part. But if not, then after one or more re-entrances, we shall be left with too small a number to make another complete winding.

When a re-entrance takes place, we have travelled a whole number of times round the armature since we have come back to the starting point. Let this be t times, so that the total travel is tG in terms of the group-space. The average pitch, $\bar{y}$, is the average travel for one group.

Hence the first winding includes $t\,G/\bar{y}$ groups, and the number of re-entrances is—

$$w = G \div (t\,G/\bar{y}) = \bar{y}/t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now, w and t must both be integers; hence $\bar{y}$ must also be an integer and a multiple of t. The various possible values of w and t are the several factors of $\bar{y}$, from unity to $\bar{y}$, but the number actually obtained in any case will depend upon G.

In the general case, where there are r pitches in the cycle—

$$\bar{y} = \frac{1}{r}(y_1 + y_2 + y_3 + \ . \ . \ . + y_r) = \text{an integer} \quad . \quad . \quad . \quad . \quad (2)$$

and the general condition for re-entrancy is that the algebraic sum of all the pitches is a multiple of their number.

We have to go round the armature $\bar{y}/w$ times for each re-entrance, and consequently must go round $\bar{y}$ times to complete the winding. . (3)

Number of Re-entrances.—If v is the number of groups in each winding, then $G = vw$. The travel for v groups is $v\bar{y}$, and, from the above, is to be equal to $t\,G$. Hence, $v = t\,G/\bar{y}$. But r groups go to each cycle, and each winding is to have a number of complete cycles. Hence v/r is an integer. But—

$$\text{Number of cycles per winding} = \frac{v}{r} = \frac{t\,G/\bar{y}}{r} = \frac{G/r}{\bar{y}/t} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

There will be a proper re-entrance for the least value of t which will make this an integer. Hence, $\bar{y}/t$ will have the greatest possible value compatible with the whole expression being an integer. Hence $\bar{y}/t$ is the highest common factor of $\bar{y}$ and G/r. That is—

$$w = \text{H C F of } \bar{y} \text{ and } G/r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Re-entrances at intermediate points of the cycle, not being allowable, are not included here, but are dealt with along with clashing.

Applying this to the case in which there are only two pitches, y_f and y_b, we have—

$$\bar{y} = \tfrac{1}{2}(y_f + y_b) \ = \text{an integer} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$
$$w = \tfrac{1}{2}(y_f + y_b)/t = \text{H C F of } \bar{y} \text{ and } \tfrac{1}{2}G \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Whence it follows that $(y_f + y_b)$ and G must be multiples of $2w$, but must have no higher common factor.

Conditions for not Clashing. (i.) 2-Group Cycle, Single Re-entrance.—But there is another way in which a proposed set of numbers might fail geometrically to give a possible winding. Starting by going down from the front end, we might find that after winding a portion of the armature we arrived at the back end of the group from which we started, instead of at the front end, an *up* place thus falling on one already occupied by a *down* one. We may call this a *clash*. Confining ourselves first to the case in which there are but two pitches in a cycle, and only one re-entrance, this will occur, if at all, after we have gone through so many pairs of groups and one pitch more. That is when we have a travel of $f(y_f + y_b) + y_b$, f being an integer. But we might get a clash at the front end after a travel of $f(y_f + y_b) + y_f$, where

f may have a different value to what it had before. These may both be included in the one general expression $f(y_f + y_b) \pm y_f$.

But to come back to the starting-point means a total travel of so many times round. Hence, when expressed in terms of the group space, it is a multiple of G, say lG, l being an integer.

Then—

$$f(y_f + y_b) \pm y_f = l\,\mathrm{G}.$$

Or—

$$f = \frac{l\,\mathrm{G} \mp y_f}{y_f + y_b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Clashing will take place if for some integral value of l there is an integral value of f, but not otherwise. Let us, therefore, study the conditions which determine whether an expression of the type—

$$\frac{l_1 x_1 \mp y}{x_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

may be an integer for some integral value of l_1; x_0, x_1, and y, being given integers.

Let

$$x_0 = l_1' x_1 + x_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

l_1' and x_2 being integers, and x_2 less than x_1. l_1' is in fact the quotient and x_2 the remainder, when x_0 is divided by x_1.

There will be some multiple of this in the series obtained by putting successive integral values for l_1 in the numerator of (9) if—

$$l_1'' x_1 \mp y = l_2 (l_1' x_1 + x_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

l_1'' and l_2 being some integers. That is, if—

$$l_1'' = \frac{l_2 (l_1' x_1 + x_2) \pm y}{x_1} = l_2 l_1' + \frac{l_2 x_2 \pm y}{x_1} \quad . \quad . \quad . \quad . \quad (12)$$

There will be such an integral value of l_1'', provided that $\frac{l_2 x_2 \pm y}{x_1}$ is an integer for some integral value of l_2. This is of exactly the same form as (9) with which we started, but x_2 is smaller than x_1. Repeating the processes (10), (11), and (12), over and over again, we get in succession—

$$\begin{aligned} x_1 &= l_2' x_2 + x_3, \\ x_2 &= l_3' x_3 + x_4, \\ &\cdots\cdots\cdots \\ x_{n-1} &= l_n' x_n + x_{n+1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13) \end{aligned}$$

and the conditions that—

$$\frac{l_3 x_3 \mp y}{x_2}, \ \frac{l_4 x_4 \pm y}{x_3}, \ . \ . \ \frac{l_n x_n \pm y}{x_{n-1}}, \text{ are all integers} \quad . \quad . \quad . \quad (14)$$

Each of the integers x_1, x_2, x_3, ... x_n, is smaller than the preceding one.

Let h be the highest common factor of x_0 and x_1. It follows from (10) and (13) that it must also be the H C F of x_1, x_2 : x_2, x_3, etc.; in fact all the x s. Hence, when the above processes have been repeated often enough, we must ultimately come to a term in the series (13)

which is equal to h. Let this be $x_n = h$. The next equation from (13) will be—

$$x_{n-1} = l_n x_n + x_{n+1} = l_n h + x_{n+1} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

But x_{n-1} is a multiple of h, and therefore the value of l_n is x_{n-1}/h, since it is the quotient when dividing x_{n-1} by x_n; and since there will be no remainder this time owing to h being a factor of x_{n-1},

$$\therefore x_{n+1} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Hence the next term of the series (14) becomes—

$$\frac{l_{n+1} x_{n+1} \mp y}{x_n} = \frac{\mp y}{h} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

and this will be an integer if y is a multiple of h, and only then. But if (17) is an integer, all the others, (14), (12), and (9), are also integers; and if it is not, none of them are.

Hence the condition that $(l_1 x_1 \pm y)/x_0$ should be an integer for some integral value of l_1, is that y must be a multiple of the H C F of x_1 and x_0; and that it should not be an integer is that y must not be such a multiple . . . . (18)

Applying this to (8), we get as the condition for no clashing to occur, that y_f must not be a multiple of the H C F of G and $(y_f + y_b)$. If y_f is not such a multiple neither can y_b be one, for any factor common to one of them and their sum must also be a factor of the other. From (7) the H C F of $\frac{1}{2}$G and $\bar{y}$ is w, and $\bar{y} = \frac{1}{2}(y_f + y_b)$ from (6). Hence the H C F of G and $(y_f + y_b)$ is $2w$. Consequently neither y_f nor y_b may be multiples of $2w$. . . . . (19)

Conditions for not Clashing. (ii.) 2-Group Cycle, Several Re-entrances.—If there is more than one re-entrance we have to make a fresh start for each winding, and therefore the above only gives the condition for no clashing to take place with another of the same winding. We must now find the additional conditions to be fulfilled in order that one winding may not clash with another. Let the groups be numbered consecutively, and the first winding start at number e_1, the second at e_2, the third at e_3, and so on . . . . (20)

The same cycle of connections is to be used for all. After one winding is wound, the vacant spaces will be cyclic as well as those that are already filled. Hence, if the second winding is started by going down a vacant space, we cannot have a down place of the second winding clashing with the first, Likewise, if the first up-wire does not clash, neither will the others. Similarly for the third and future windings.

If—

$$\left.\begin{array}{l} f(y_f + y_b) = l\mathrm{G} + (e_2 - e_1), \ \textit{i.e.}, \text{ if } f = \dfrac{l\mathrm{G} + (e_2 - e_1)}{y_f + y_b} \\ \text{or—} \\ f(y_f + y_b) + y_b = l\mathrm{G} + (e_2 - e_1), \ \ \text{,,} \quad \text{,,} \ f = \dfrac{\mathrm{G} + (e_2 - e_1 - y_b)}{y_f + y_b} \end{array}\right\} \quad (21)$$

where f and l are some integers, not necessarily the same in each case, then the proposed starting-place will not be vacant.

Again, if—

$$\left.\begin{array}{ll} f(y_f+y_b)=lG+(e_2-e_1)+y_b, \text{ i.e., if } f=\dfrac{lG+(e_2-e_1+y_b)}{y_f+y_b} \\ \text{Or if—} \\ f(y_f+y_b)+y_b=lG+(e_2-e_1)+y_b, \text{ ,, ,, } f=\dfrac{G+(e_2-e_1)}{y_f+y_b} \end{array}\right\} \quad (22)$$

the places for the up-wires will be already occupied.

In order that there may be no clashing, there must be no possible integral values of any of these expressions for any integral values of l. (18) gives, as the condition for this, that the H C F of G and (y_f+y_b) must not be a factor of either (e_1-e_2), $(e_1-e_2-y_b)$, or $(e_1-e_2+y_b)$. This condition must also be fulfilled when we put instead of e_2 and e_1 the starting-points of any two of the several windings. In (19) we saw that this H C F was $2w$. Hence $2w$ must not be a factor of the difference between the starting-points of any two windings, nor of the sum or difference of that difference and either pitch . . . . . (23)

Conditions for not Clashing. (iii.) Multi-Group Cycle, Single Re-entrance.—Similarly, if there are r pitches in a cycle, $y_1, y_2, y_3, \ldots y_r$, but only one winding, we might have a clash after going through the cycle so many times and one pitch more, or two more, or three more, and so on up to $(r-1)$ more. Also we might start at any point of the cycle, so the extra one might be any one, the extra two any consecutive two, and so on. We can, however, write down the condition at once, because it is obvious that the sum of all the pitches will take the place of (y_f+y_b) in (8) and (19), while the sum of the extra ones, whether one or more, takes the place of y_f. Hence, in order that there may be no clashing, the H C F of G, the number of groups, and the sum of all the pitches in one cycle, must not be a factor of any individual pitch, of the sum of any two, or any three, or any four, etc., up to any $(r-1)$, consecutive pitches taken in cyclic order. It is really only necessary to test this up to the sum of any $\frac{1}{2}r$ consecutive pitches, because if the sum of any q of them satisfies the condition, it must also be satisfied by the sum of the remaining $(r-q)$.

The sum of all the pitches in a cycle is $r\bar{y}$, and the H C F of G/r and $\bar{y}$ is w. (See (2) and (5).) Hence the H C F of G and the sum of all the pitches is rw. Consequently rw must not be a factor of any of the quantities mentioned above . . . . (24)

A clash with an even number of pitches beyond a complete cycle would really be a re-entrance if the winding is then stopped, but as it would break the cycle of connections it would not give a regular winding.

Conditions for not Clashing. (iv.) Multi-Group Cycle, several Re-entrances.—In the most general case wherein there are any number of pitches in a cycle, and any number of re-entrances, if any one group falls on a vacant place, the corresponding groups in all the other cycles will also be right. Proceeding in the same way as before, it is easily seen that the H C F of G and the sum of all the pitches in one cycle must not be a factor of the difference between the starting-points of any two windings ; nor of the sum or difference of that difference and any single pitch, the sum of any two, three, four,

etc., pitches taken in cyclic order. But the H C F of G and the sum of the pitches is rw. (See (24).) Hence rw must not be a factor of any of these quantities . . . . (25)

Conditions (25) are in addition to (24). It is thus seen that the number of conditions to be met when there is a number of pitches in each cycle, and a number of re-entrances, becomes very large, and that consequently the possible numbers are limited, and will take some trouble as a rule to find. This combination is almost never met with in practice.

Electrical Conditions.—The main object of an armature is to generate an E.M.F., and so the connections must be such that going from brush to brush the several E.M.F.'s are all added together, and that they all act one way round the winding. As we go through the winding we travel round the armature, but at the same time we gradually creep along the pole-pitch. Starting just inside the centre line between a pair of poles, after going through one cycle, the next starts with a group at a pole of the same name as the first, but a little inside the centre line, the third cycle will start still further in, and so on. Now, so long as the cycles begin at the same kind of pole, the E.M.F.'s in their first groups will always be in one way, but as soon as the creep exceeds the pole-pitch the E.M.F. in them is reversed. Hence the creep for that part of the winding between two consecutive brushes (*i.e.*, consecutive relative to the winding) should be equal to the pole-pitch if there is to be no counter E.M.F.'s in the leading groups of the cycles.

Now, one or two conductors in any circuit with counter E.M.F.'s would not matter greatly. Let us therefore see whether the average creep per circuit may be a little more, or less, than the pole-pitch. Let it be $(G + d)/p$, where d is an integer. There will be d/p leading groups in this circuit with a counter E.M.F. in them. But the next circuit will start this amount out of place, and will therefore overlap the pole-pitch by twice this at the other end, and so on for the others, the last (c/w *th*) one of this winding having $(c/w)\ (d/p)$ first groups with counter E.M.F.'s.

But the total creep for a complete winding must be a multiple of the pole-pitch, since we come back to the starting-point. Let it be kG/p, where k is an integer. Then—

Creep for one winding = Creep for c/w circuits.

Or—

$$\frac{kG}{p} = \left(\frac{G+d}{p}\right)\frac{c}{w} \quad \ldots \ldots \ldots \quad (26)$$

$$\therefore\ \frac{cd}{wp} = \frac{G}{p}\left(k - \frac{c}{w}\right) \quad \ldots \ldots \ldots \quad (27)$$

But c/w is an integer, being the number of circuits in each winding. Hence cd/wp is a multiple of the pole-pitch G/p, since k is also an integer. That is, cd/wp is either 0, or G/p, or $2\,G/p$, etc. But this is the number of leading groups with counter E.M.F.'s in the last circuit under the assumed conditions, and for anything like as many as G/p to be opposite the wrong pole would of course not be allowable. Taking $2\,G/p$, the wires in this circuit would be mostly rightly placed,

but an intermediate circuit would then have the unallowable G/p. Hence cd/wp must be taken as zero, *i.e.*, d must be zero if c is not. If c is zero, the creep for one winding is also zero, from (26), and consequently the creep for a cycle must be zero. Hence, the average creep per circuit must be equal to the pole-pitch, but the creep for any individual circuit will differ slightly from this if the brushes are not symmetrically set.

Each circuit contains on the average G/c groups, and G/rc cycles. (Not necessarily integers.) Hence, the average creep per cycle is $(G/p) \div (G/rc) = rc/p$.

$$\therefore\ r\bar{y} = \text{Sum of all the pitches in one cycle.}$$
$$= \text{Travel for one cycle.}$$
$$= \text{Motion from pole to pole} + \text{Creep, both for one cycle.}$$
$$= \frac{2mG}{p} \pm \frac{rc}{p} = \frac{2mG \pm rc}{p}.$$
$$\therefore\ \bar{y} = \frac{2mG \pm rc}{pr} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (28)$$

where m is an integer, and may be positive, negative, or zero. $\bar{y}$ must be an integer. Hence c must be a multiple of the H C F of $2G/r$ and p. (From 18.) The motion from pole to pole for one cycle must be over an even number of poles, since successive cycles must start at similar poles, except at the places where one is just on the one side of the dividing line and the other just on the opposite side. Hence the 2 in $2mG$.

There is no use of considering values of $\bar{y}$, y_f, y_b, etc., greater than $\frac{1}{2}G$, as such a pitch could be equally well expressed by a number less than $\frac{1}{2}G$ with the opposite sign. Hence we may limit m to values less than $\frac{1}{4}pr$ when m and c are taken with the same sign, and to values not greater than $\frac{1}{4}pr$ if they have opposite signs.

2-Group Cycle. Collected Results.—Applying these results to the case in which there are but two pitches in a cycle, and collecting the conditions, we have :—

Refer to—

(28) and (6) $\bar{y} = \frac{1}{2}(y_f + y_b) = \dfrac{mG \pm c}{p} \quad \ldots\ldots\ldots\ldots \quad (29)$

$$\left.\begin{aligned} y_f \text{ or } y_b &= y_1 = \bar{y} + \frac{nG + a}{p} \quad \ldots\ldots\ldots\ldots \\ y_b \text{ or } y_f &= y_2 = \bar{y} - \frac{nG + a}{p} \quad \ldots\ldots\ldots\ldots \end{aligned}\right\} (30)$$

Where—

m is an integer, positive, negative, or zero, but not greater than $\frac{1}{2}p$ if taken with the opposite sign to c, and less than $\frac{1}{2}p$ if taken with the same sign as c . . . . . . (31)

n is an integer, of the same sign as m, or zero, but not greater than $(\frac{1}{2}p \pm m)$ when the greater of c and a has the opposite sign to m, and less than $(\frac{1}{2}p \pm m)$ if they have the same sign . . . . (32)

a is an integer, positive, negative, or zero, but not greater than $\frac{1}{2}$G . . . . (33)

c, p are even integers . . . . (34)

G must be a multiple of $2w$ . . . . (35)

(7) $\bar{y}$ must be a multiple of w, but have no higher factor in common with $\frac{1}{2}$G . . . . (36)

(29) ∴ $(mG \pm c)$ must be a multiple of pw . . . . (37)

(18) ∴ c must be a multiple of the H C F of G and pw (38)

(30) y_1, y_2 must be integers . . . . (39)

∴ $(nG + a)$ must be a multiple of p . . . . (40)

(18) ∴ a must be a multiple of the H C F of G and p . (41)

(19) y_1, y_2 must not be multiples of $2w$ . . . . (42)

(*) ∴ $(nG + a)$ must not be an odd multiple of pw if $\bar{y}/w$ is odd, nor an even multiple of pw if $\bar{y}/w$ is even . . . (43)

(23) $(e_2 - e_1)$, etc.. must not be multiples of $2w$ . . . . . . (44)

(23) $(e_2 - e_1 \pm y_1)$, etc., must not be multiples of $2w$ . . . . (45)

The condition (19) or (42) that y_f should not be a multiple of $2w$ can be reduced to (43) as follows. $\bar{y}$ is a multiple of w. Consequently $(nG + a)$ must not be an odd multiple of pw if $\bar{y}$ is an odd multiple of w, as then the sum and difference of $\bar{y}$ and $(nG + a)/p$ would be multiples of $2w$. Similarly $(nG + a)$ must not be an even multiple of pw if $\bar{y}$ is an even multiple of w.

If y_f and y_b have opposite signs we get a lap-winding, and if they have the same sign it is a wave-winding. Hence lap-windings correspond to m being less than n, and wave-windings to m being greater than n. If they are equal, which is only possible with ring-windings, then a must be greater than c for laps, and less for waves.

Multi-Group Cycle. Collected Results.—In the general case where there are r pitches in a cycle, $y_1, y_2, y_3 \ldots y_r$, in cyclic order, then :—

Refer to—

(2) and (28) $\bar{y} = (y_1 + y_2 + \ldots y_r)/r = \dfrac{2mG \pm rc}{pr}$ . . . . (46)

$$\left.\begin{aligned} y_1 &= \bar{y} + (n_1 G + a_1)/p \\ y_2 &= \bar{y} + (n_2 G + a_2)/p \\ &\ldots\ldots\ldots\ldots\ldots \\ y_r &= \bar{y} + (n_r G + a_r)/p \end{aligned}\right\} \quad (47)$$

Where—

m is an integer, positive, negative, or zero, but not greater than $\frac{1}{2}pr$ if taken with the opposite sign to c, and less than this if taken with the same sign . . . . (48)

$n_1, n_2, \ldots n_r$, are integers, positive, negative, or zero, but not greater than $(\pm \frac{1}{2}p - 2m/r)$ when the greater of c and a has the opposite sign to $(2m/r + n)$, and less than $(\pm \frac{1}{2}p - 2m/r)$ if they have the same sign, $\frac{1}{2}p$ being taken with the same sign as n . . . . . (49)

$a_1, a_2, \ldots a_r$, are integers not greater than $\frac{1}{2}$G. . . . (50)

(46) $(n_1 + n_2 + \ldots + n_r)G + (a_1 + a_2 + \ldots + a_r) = O$ . . (51)
c, p are even integers, and c an even multiple of w . . . (52)
G must be a multiple of rw . . . . (53)
(5) $\bar{y}$ must be a multiple of w, but have no higher factor in common with G/r . . . . (54)
(46) ∴ $(2mG \pm rc)$ must be a multiple of rpw . . . . (55)
(18) ∴ c must be a multiple of the H C F of $2G/r$ and pw . . (56)
(47) $y_1, y_2, \ldots y_r$, must all be integers . . . . (57)
∴ each $(nG + a)$ must be a multiple of p . . . . (58)
(18) ∴ each a must be a multiple of the H C F of G and p . . (59)
(24) rw must not be a factor of $y_1, y_2, \ldots y_r$ . . . . (60)
Nor of $(y_1 + y_2), (y_2 + y_3) \ldots (y_r + y_1)$ . . . (61)
Nor of $(y_1 + y_2 + y_3)$, etc., to $(y_r + y_1 + y_2)$ . . . (62)
Etc., etc., up to
$(y_1 + y_2 + \ldots + y_{r-1})$, etc., to
$(y_r + y_1 + y_2 + \ldots y_{r-2})$ . . . . (63)
(25) rw must not be a factor of the difference of the starting-points of any two windings, not necessarily consecutive ones . . . . (64)
Nor of the sum, or difference, of that difference and any of the quantities (60), (61), (62), and (63) . . (65)

It is comparatively rare to have more than two pitches in the cycle, and we almost never have more than four if only the groups are numbered. Of course, if all the conductors are numbered there would be as many pitches in each cycle as there are conductors, but even then there would not in most cases be more than two different values at each end.

Connections to Commutator.—The ends of each cycle of connections should go to segments of the commutator, the relative position of the several segments round the commutator being the same as the relative positions round the armature of the sections to which they are joined. In some cases it would also be feasible to connect to the commutator only at every second, or every third, etc., cycle, provided these numbers are aliquot parts of the whole number of cycles. Or again, intermediate points might have their own segments. The latter might be carried so far as to have a segment for every joint, but as it would be inconvenient to have segments connected to the back connectors this is not done.

With certain windings, each end of a section is connected to several segments of the commutator. For instance, when the number of sections is a multiple of the number of poles and there are more than two poles, for each section there will be another in exactly the same condition as regards the E.M.F. in it, and at the same potential, opposite each of the poles of similar name. Hence the corresponding segments may be joined together. Or again, in certain two-circuit windings in which the travel per section is greater than twice the pole-pitch, it is necessary to join each section to more than two segments, and to have the number of segments a multiple of the number of

sections instead of equal to it. Each segment is then cross-connected to others at regular intervals round the commutator.

Ring Windings.—In ordinary ring-windings both the outside and inside groups must in general be numbered to make the formulæ apply. If these are numbered alternately, we get the ordinary Gramme ring by putting $m=0$, $n=0$, $a=0$, and $c=p$, in (29) and (30). This shows that there will always be p circuits with such a winding.

By taking other values for m, n, and a we can get a large variety of ring-windings with p circuits, that is of parallel grouped rings. We may, however, get any other even number of circuits by a suitable choice of m and G.

With multipolar rings any coil may be connected to another at a pole of the same sign, or to one at a pole of the opposite sign. The former kind, of which the simple ring is really a particular case, is often called the "long-connection type"; while the latter, owing to the adjacent pole being the one usually chosen, is known as the "short-connection type." In the former case the inside of one coil is joined to the outside of the next, and a cycle may include only a single coil, although four-group cycles are not uncommon with ring-windings. Both active and shielded groups must be numbered with the long-connection type. In the short-connection type the outsides of two coils are joined together and the insides of two coils together, the latter connection being most conveniently made at the back, and in this case only the active conductors need be numbered. Now every cycle of connections must start in the same way, so there must be at least two coils in a cycle, and if both the active and shielded groups are numbered there must be at least four groups in the cycle. It will suffice, however, to only number the active groups, and thus reduce what would otherwise be a four-group cycle to the simpler case of a two-group cycle. Down and up then have reference to the way in the active groups. With a little thought it will be seen that this type of ring-winding forms a sort of cross between an ordinary ring and a drum, the separate coils being wound as in rings, but the connections between the several coils arranged as in a drum. In fact, when the inner connections (or rather what would be the inner ones if made at the front) are made at the back, it actually becomes a drum-winding in the case in which there is only one active conductor in each coil. In the general case of ring-windings there are no limits to the values of y_1, y_2, etc., other than those set forth above, but when only the active groups of a short-connection ring are numbered, then they are subject to the same limitations as drum-windings.

Drum Windings.—In a drum-winding each conductor must be joined to conductors at poles of the opposite sign to the pole at which it is. Hence y_1, y_2, etc., must be approximately equal to an odd number of pole-pitches. Hence $(2m/r + n)$ must be odd in each case. In other words, if $2m/r$ is even, n must be odd, and *vice versâ*.

It is very seldom that there are more than two groups per cycle in drum-windings, and so we may confine ourselves to the simple two-group cycle, in which $2m/r$ becomes simply m. For lap-windings $(nG + a)$ must be greater than $(mG \pm c)$ in order that the pitches may

have opposite signs, while for wave-windings it must be less than this. Remembering that $(m+n)$ may not be greater than $\frac{1}{2}p$, and that $(m+n)$ must be odd, we get the following possible values of m and n :—

POSSIBLE VALUES OF m AND n FOR TWO-GROUP CYCLE, DRUM WINDINGS.

No. of Poles.	2			4			6			8			10			12			14			16		
	m	n	c'	m	n	c'	m	n	c'	m	n	c'	m	n	c'	m	n	c'	m	n	c'	m	n	c'
Lap Windings. $n > m$	0	1	2	0	1	4	0	1	6	0	1	8	0	1	10	0	1	12	0	1	14	0	1	16
							0	3	6	0	3	8	0	3	10	0	3	12	0	3	14	0	3	16
													0	5	10	0	5	12	0	5	14	0	5	16
																			0	7	14	0	7	16
							1	2	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2
													1	4	2	1	4	2	1	4	2	1	4	2
																			1	6	2	1	6	2
													2	3	2	2	3	2	2	3	2	2	3	2
																			2	5	2	2	5	2
																			3	4	2	3	4	2
Wave Windings. $n < m$	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2	1	0	2
							2	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
							3	0	6	3	0	2	3	0	2	3	0	6	3	0	2	3	0	2
													3	2	2	3	2	6	3	2	2	3	2	2
													4	1	2	4	1	4	4	1	2	4	1	4
																			4	3	2	4	3	4
													5	0	10	5	0	2	5	0	2	5	0	2
																			5	2	2	5	2	2
																			6	1	2	6	1	2
																			7	0	14	7	0	2

If m is a multiple of p, it follows from (29) that c must also be a multiple of p. That is, we can then only get parallel groupings and multiple circuit windings. Applying (18) to (29) we find that, in order that there may be some possible value of G for a given number of circuits and poles, and a given value of m, c must be a multiple of the H C F of m and p. The columns headed c' in the table give the smallest number of circuits greater than zero possible for the corresponding values of m and p. This is the H C F when the latter is even, and twice the H C F when it is odd. The only other numbers of circuits possible in each case are multiples of c'. From this we see that any even number of circuits may be obtained in a two-pole armature with either a lap- or a wave-winding, but these can only be distinguished from each other when it is agreed to measure y_f and y_b by the shortest way round, as we have done. If this restriction is removed, lap- and wave-windings become the same thing in the case of a two-pole drum.

With four poles, on the other hand, we can only obtain multiples of four circuits with a lap-winding, but any even number with a wave, and consequently a series grouping with four poles must be a wave-winding. With a higher number of poles either a wave or a lap may be chosen; but with the latter, one at least of the pitches must span over several poles. This would be very wasteful of copper in a bar armature, but might be used with wire-wound armatures having many turns per coil, if any advantage were to be gained by it.

It is not often that either m or n, or $(m+n)$, is greater than unity; so

in practice for a series grouping, or any other number of circuits not a multiple of p, a wave-winding would be adopted. Lap-windings are generally employed for parallel groupings, or windings with a multiple of p circuits. Wave-windings may also be used for this, but they have several peculiarities. For instance, when p brushes of ordinary width are used it will be found that the coils are not shorted through the tips of one brush, but through the connection between two brushes of the same polarity. It is also possible with them to have only two sets of brushes by making them span over a much larger arc on the commutator, but this is attained at the expense of the symmetry of the circuits, and with many circuits it would not be allowable for this reason.

The remaining constant a would usually be the smallest compatible with the conditions (39), (40), (41), and (45), but it may differ a little from this. That value of a which makes the back pitch most nearly equal to the pole pitch gives what may be called an ordinary winding, whereas other values will give a chord winding.

Either y_1, or y_2, if unequal, may be taken as the front pitch y_f, and the other for the back pitch y_b. Choosing for y_b the one most nearly nearly equal to the pole pitch, or a multiple of it, by taking suitable values of m, n, and a brings the coils under commutation nearest to the neutral zone, assuming the brushes to be properly set, while the other values cause the shorted groups between any pair of poles to be more widely separated, and slightly removed from the neutral zone. When the armature is made up of a number of former wound coils the width of the coil is as a rule made equal to the back pitch; and so shortening the latter, by reducing the span of the coils, diminishes the length and weight of the ends and the space they occupy. It also facilitates putting the coils in place in a slotted armature, owing to the smaller angle between the two slots into which a coil has to go; and, by reducing the number of groups overlapped by each coil, makes the winding more accessible and the insulation easier. In any case it will simplify the end connections by reducing the number of crossings, diminish the armature reaction, and lower the maximum potential difference between adjacent groups, to take both y_f and y_b as small as possible, but especially y_b. The smallness of y_b is limited by the amount of differential action due to counter E.M.F.'s in one side of some of the sections, which can be permitted, and by the narrowing of the commutating zone caused by its removal from the neutral zone. For these reasons y_b should never be less than the pole span, although y_f may be.

Rotaries.—For rotary converters, in addition to the above conditions, the number of sections in two consecutive circuits, that is between one brush and another of the same polarity (which would be the same brush if there were only two brushes altogether), ought to be divisible in the same way as the period is to be divided for the different phases on the alternate-current side. Thus, for a single phase (really two phases in opposition as far as the armature is concerned), this number of sections must be a multiple of 2; for two phases in quadrature, or four phases in successive quadrature, it must be a multiple of 4; for three phases in

ternature, a multiple of 3; and for three phases in sexature, or six phases in successive sexature, a multiple of 6. Each such part of the winding between two successive + brushes, or two successive − brushes, is then divided into that number of parts, and the points of division joined down to the slip-rings, of which there will be two for single-phase, four for two- or four-phase, three for three-phase, and six for six-phase. The corresponding points of the different pairs of circuits are joined to the same slip-rings.

Rotaries are, however, sometimes two circuit windings, which cannot always be divided in the desired way, if the tappings are to be made at one end only. They are then divided as nearly as possible in the above ratio, but the phase differences will be slightly different from the desired values.

Alternators.—Any winding would serve as an alternate-current winding if joined down to slip-rings, or terminals, in the manner described above, but there would then be several circuits in parallel, and this is found to be inadvisable for alternators. Consequently most of the windings actually employed for alternators are open coil windings, and they are not necessarily regular. But it will be found that almost all those to be met with in practice are either regular windings, or can be analysed as a combination of regular windings.

In the beginning it was stipulated that c might be zero. At first sight it might be thought that such a thing would have no meaning, but it really indicates that there will be no places at which the current wants to leave or enter the winding, although the conductors will still have E.M.F.'s in them. An o-circuit winding is thus one in which all the E.M.F.'s act in the same way round, and so it is shorted on itself. But if a break be made in that winding, say by leaving out the last connection, we get an open coil winding suitable for a single-phase alternate current, the free ends being joined to the slip-rings or terminals, as the case may be. It will be found, however, that this will only take up r groups per pair of poles, and that a cycle must cover an even number of pole pitches. Hence there must be twice as many connections in a cycle as there are groups per pole if the winding is to be completed in going once round, when it re-enters on itself. That is, we must take $r =$ twice the number of groups per pole per phase, and $w =$ number of phases, for a polyphase winding of this kind. This is a lap winding.

But many windings have a travel of several times round for each phase, and they may be obtained in the following way. Put $w = 2/r$ times the number of groups per pole, which must be a multiple of the number of phases wanted, r being chosen small enough to allow of this, it generally having the value 2. Each of the w windings thus obtained is then broken at any convenient point, and we have w different phases. These are reduced to the required number by joining those most nearly in phase, *i.e.* the adjacent ones, in series so as to form a number of identical sets equal to the number of phases. This gives a wave winding, or a combined lap and wave, and several modifications may be obtained according to the way in which the several sub-phases are combined together.

We may get some of these windings in another way by taking r as the number of groups gone through in going once round the armature. Usually all the pitches are alike, or may be divided into several sets, each forming a sort of inner cycle except the last one, which would have to be different to the others ; but in applying this second method it is to be remembered that the winding need not be, and usually is not, re-entrant, and consequently y is not necessarily an integer, and the other conditions deduced from this need not be complied with. The first method is probably the simplest for getting out such a winding, but the latter can be easily enough applied after the winding is designed.

Besides these different classes of alternate-current windings there are a few odd ones sometimes met with which are not regular at all, and which could only be brought under the general formula by taking the whole winding as one cycle, and this of course would not assist us in any way to design the winding. Others, again, introduce some irregularity at the junctions of the several components of the winding when analysed in the way described above. This consists of interchanging some of the groups from one sub-winding to another of the same phase, but there does not appear to be any particular advantage in doing this.

In getting equation (28) we assumed that it was an even number of pole pitches from one pole to another of the same kind. Hence when we are dealing with homopolar fields, such as that of the Mordey Alternator, we must take $p =$ number of poles on both sides, or twice the number on one side, and then the formulæ will apply without any modification.

Open Coil Armatures.—An open coil continuous-current armature may be regarded as a polyphase generator with commutators added to rectify the currents, and so they may be treated in the same way as open-coil alternators, with the difference that the free ends are joined to separate segments of the commutator. The commutators may be so arranged as merely to commute the several phases in turn and join them in series, or it may put two, or more, coils in parallel at the instants when their E.M.F.'s are about equal. The little hand generator supplied with the Evershed Testing Set is an example of the former mode of doing; while the Brush arc light dynamo has four, or six, phases, and the Thomson-Houston three joined star-fashion, which are treated in variations of the second way.

Disc Armatures. Pole Windings.—Disc windings may be classed either along with rings or with drums, according as the current returns through shielded conductors, or through active ones. Hence, so far as the numerical properties of the windings are concerned, the same rules will apply as to cylindrical armatures.

Pole windings are really exaggerated toothed core armatures, and therefore may be treated as such.

A METHOD OF STUDYING ARMATURE WINDINGS BY MEANS OF WINDING DIAGRAMS.

By DAVID ROBERTSON, B.Sc., Associate.

Winding Diagrams.—There are three classes of winding diagrams in general use. First there is what we may call the *circular diagram*, which is practically an end view of the armature. Then we have *developed diagrams*, in which the armature periphery is folded out flat. And lastly there is the *radial diagram* in which the active conductors are represented by radial lines, the front connections being drawn inside one circle, the back connections outside another concentric with the first, and the radial lines for the active conductors in between. To these the author would add a fourth, which may be termed a *current diagram*, in which as a rule active conductors or groups of conductors[1] only will be shown, and the connections left out. It might be either circular, developed, or radial, but is most conveniently taken as an end view of the developed diagram. It is particularly useful in studying the changes in the distribution of the current round the periphery during the different stages of commutation, or with different widths or arrangements of brushes. A large number of diagrams can be made in a comparatively short time if the connections are omitted, but these can be easily filled in when required.

Winding Tables.—The first step is to make a *winding table* for the proposed winding, showing the position of the commutator segments. This can be made up from the chosen pitches without any reference to a diagram, it being understood that the groups are numbered consecutively round the armature, and that the segments are distinguished by the letters of the alphabet taken the same way round. The examples at the end of this paper show the best form of winding table, that being only very slightly modified from those given by S. P. Thompson, Kapp, and others. In the tables, the letters B, F, in the upper row come above the divisions between the columns of figures, and they indicate that the corresponding junction is made at the back or front end respectively, while the letters at the heads of the columns show whether we go down or up in that group when tracing out the winding in the direction chosen, and do not refer to the way of the current in the conductors. Columns for the commutator segments come in under F between the columns of figures. Crossing a vertical line in the table corresponds to crossing an end of the armature. That at the front end is divided into two stages, first to the commutator, and then to the next group. The table for the first example (p. 956) may thus be read as follows: Start at *a*, cross the front, go down 1,

[1] The word "group" is used throughout this paper to denote that part of the winding which is treated as a unit in the diagrams and tables, whether it consists of a group of conductors or of a single conductor only.

cross the back, up 8, cross the front to *h* and then to 15, down 15, and so on.

The actual position of the segment *h* relative to the groups 8 and 15 will depend upon the form of connectors used. It may either be at the same radius as 8, the same one as 15, midway between them, or at any other position; but this will only alter the position of the brushes relative to the poles, and will not affect the character of the winding, nor the distribution of the current at the pole faces. It is usually either beside one of the groups to which it is joined, or else midway between them. The mid position makes the connectors symmetrical, and brings the brushes to the middle of the poles, which is the most convenient place in bipolar machines of the under, or over, types.

In making out the table, the numbers are first written in their proper places by starting with 1, and then adding the back and front pitches alternately until the starting point is again reached. A fresh start must be made for each distinct winding, and it is well to begin it on a new line. Next fill in the letters for the commutator segments. The order in which they appear in the table will depend on the nature of the winding, but it will be the same as the order of the conductors to which they are connected. It is convenient always to start from segment *a* and then go down No. 1. If there are only two groups per section, as in the examples, we then know that *b* comes before 3, *c* before 5, and so on. The position of the letters for any other number than two groups per section can be found in a similar way, the numbers following consecutive letters going up by that number instead of by two. A wave winding has been chosen for the first example better to illustrate this method of placing the letters, as an ordinary lap winding would give the letters running *a b c d*, etc., in the same way as the numbers, and the necessity for taking it up in this manner is not so apparent. Of course as soon as the cyclic order of either the numbers or letters is seen, advantage may be taken of any peculiarity to fill in the rest of the table more quickly. Thus in Example I., after putting in one or two letters it is seen that they are consecutive, but backwards, and so the rest may be written down at once.

Position of Brushes.—The next step is to settle what segments are to be in contact with the brushes at some particular instant, say the instant when the centre line of a negative brush coincides with the centre line of the segment *a*. Whatever number of brushes there may be, the angle between consecutive ones will be equal to the pole pitch, or a multiple of it, and so the positions of the centre lines of the other brushes relative to their respective segments, and the names of these segments, can be determined by dividing the number of segments in the proper ratio. If the brushes are not symmetrically set their centre lines will not coincide with these positions, but since their position can be referred to any line having a fixed relation with them, we shall take as our reference lines the lines that ought to be at the centres, instead of the actual centre lines. These reference lines will be termed the *index lines* of the brushes. After the index lines have been fixed, the names of the several segments in contact with each brush can be found

from a knowledge of the brush width and how it is disposed about the index line.

Circuit Tables.—Now make up a *circuit table* for that position thus: Look up segment *a* in the winding table, and starting from it write all the numbers in a row, in the same order as in the winding table, until we reach a letter denoting a segment in contact with another brush of opposite polarity. If there are no coils shorted through that brush, start a new row, keeping the figures in columns, but write it backwards this time; and so on, a new row being started every time we come to an opposite brush, and successive rows being written in opposite ways. When all the winding has been taken up, there will then be a row for each circuit in the armature at that instant. Segment *a* being supposed in contact with a negative brush, the first, third, fifth, etc., columns are headed D, and the second, fourth, sixth, etc., headed U, to indicate the way of the currents in the wires. If any sections are shorted, the corresponding groups should be placed in a special column at the side, and the segments in contact with the brushes should also be shown in columns. These two sets of extra columns are headed *Sh* and *Seg* respectively.

The connecting lines between the different numbers represent the connections that exist between them in the armature, and the heavy lines represent the brushes. It will be noticed that the downs are alternately odd and even numbers in successive circuits. This is always the case when the pitches are odd, but not when they are even.

When a brush touches two segments at once it shorts any groups that lie between these segments in the winding unless a brush of the opposite kind intervenes. The numbers shorted can always be obtained from the winding table with the greatest ease. When there are more than two brushes, a short may take place through the connection between two brushes as well as, or instead of, through the tip of one only. This is characteristic of multipolar wave windings when more than two brushes are employed.

Construction of the Current Diagram, etc.—Draw two lines at right angles to each other, O X horizontally, and O Y vertically. See Fig. 1 (p. 957). Set off downwards from O a length O O′ to represent that portion of a revolution during which it is desired to study the commutation changes, and draw another horizontal line O′X′. It is convenient to take O O′ as a whole number of commutator segments, but a complete revolution, or any number of revolutions, may be shown. In most cases it is quite enough to represent a number of segments equal to the least number that can be in contact with a brush at once, as this will show all the stages from the commencement of a short to the end of a short for at least one section. In the examples, two segments have been represented, and it will be seen that the lower half of the diagram is merely a repetition of the upper half, with different numbers in each case, except in Fig. 5 (p. 965), in which each section is shorted by two brushes at once, and so the shorts are of longer duration.

Next, to the left of O O′ draw as many vertical lines as there are

brushes, *i.e.*, two in this example (Fig. 1), A B and C D. The spaces between these lines, including OO′, are to represent the portions of the commutator in the neighbourhood of the several brushes. On the line O X we shall represent the condition of affairs at the instant given in the first circuit table, *i.e.*, the instant when the index line of a negative brush is at the centre of *a*. Hence O X, the index line for that instant, must be the centre line of *a*. We may therefore set off from A the positions of the centre lines of the other segments near it. The relative motion of the commutator and brushes is to be shown vertically on the diagram, and it is most convenient to regard this as a motion of the brushes back in the opposite way to the numbers and letters, instead of the forward motion of the commutator past the brushes which it actually is. The index line is thus supposed to move down as the armature rotates, and consequently the sequence of the letters must be upwards. We thus get the centre lines of the segments *h*, *g*, and the heavy lines dividing them. Similarly for each of the other parts of the commutator, set out in the proper row, the position of the segment at the brush relative to the index line at the instant considered, and mark off the other segments from it. In this example both rows are alike, since the number of segments is divisible by the number of poles, but in examples V., VI., and VII., their positions differ by a quarter segment in successive ones.

Now set off from each edge of the segments, outwards, the half-width of the brush that is at that part of the commutator. If the index line is not also the centre line of the brush, then set up from the top edges of the segments the projection of the backward tip of the brush (*i.e.*, the lower tip in the diagrams) behind the index line, and downwards from their lower edges that of the forward tip ahead of the index line. Backward is here used to denote the tip which is pointing against the rotation of the armature, that is the one which makes contact with the segments; and forward refers to the other, which points in the way of the rotation, and which breaks contact with the segments. These are indicated by dotted and broken lines respectively. In many cases it is sufficient to neglect the thickness of the insulation, and to set off these distances from the dividing lines.

As soon as the index line has passed a dotted line the brush comes into contact with another segment, and as soon as it passes a broken line the brush breaks contact with the rear segment. We thus get the instants corresponding to the commencement and finish of the several shorts.

Along O X plot out a number of equal lengths representing the space occupied by each conductor, or group of conductors, round the periphery of the armature. Number them consecutively, beginning with a number about midway between the brushes in the circuit table, and commencing at 1 after reaching G. As a rule, a little more than a complete armature should be shown, a few groups being repeated at the right hand end which have been already shown at the left. By the time that the index line has gone from OX to O′X′, that is two segments' width in all the examples, group No. 1 will have moved towards the right by a corresponding amount. Set this distance, O′ M along

O′X′, and draw sloping lines through each of the divisions in OX parallel to OM. The spaces between these lines represent successive positions of the cross-sections of the groups during the time under consideration, the relative position of the index lines and commutator being shown at the same time on the left. It is easiest to plot the diagram on squared paper, making use of the divisions ruled on it.

In Fig. 1 the conductors move along four group spaces, while two segments are passing the brushes. Consequently at the end of that time No. 1 is in the position that was occupied by No. 5 at the beginning. As the index line travels down from A C, it simultaneously comes to the dotted lines E F, and so the segments *h d* are brought into contact with their respective brushes. From the winding table it is seen that *ha* will short (8–1), while *de* will short (16–9). Projecting across the conductors from E F we mark the position at which these groups commence to be shorted. The shorts will last until the index line gets to G and H, when *a* and *e* leave the brushes. G and H therefore give the position at which these groups are again thrown into circuit. Similarly (6–15) and (14–7), the groups connecting *gh* and *cd* respectively, are shorted while the index line travels from I J to K L. The groups shorted by the negative brushes are shaded by lines sloping in the same way as the middle bar of the letter N, and those shorted by the positive brush in the opposite way, throughout the space for which they are shorted. The shaded parallelograms thus obtained show the times and positions during which the corresponding groups are shorted.

When the shorts are symmetrically disposed, the vertical centre line of all at one place is the centre line between the poles if there is no lead. Any desired amount of lead may be allowed for by setting the poles back by a corresponding amount. If the shorts are not symmetrical, which is generally the case when there are fewer brushes than poles, or when the brushes are not properly set, the centre lines of the interpolar spaces, if there is to be no lead on the whole, should be placed so that the shorts are as much on one side at one place as they are on the other side at another place.

The way of the current in the other groups can be filled in from the circuit table for the position to which it refers, and for other positions it may be got by remembering that the current is reversed during a short. It is also possible to have a reversal without a short. For instance, we would get this in Example IV. if the brushes were less than one segment in width, but such cases are not of practical importance, since sparkless collection would then be impossible. With care it is possible to dispense with the circuit table so far as getting the direction of the current is concerned, and to work wholly from the winding table, but the circuit table brings out other points as to the symmetry of the circuits and voltage per segment, which are not so apparent otherwise.

Vertical dotted lines may be drawn from the edges of the poles to divide the space into regions where the E.M.F. is down and where it is up. There will of course be a little E.M.F. beyond the limits of the

poles, especially at the horns, which are strengthened by armature reaction. The curve for the distribution of the flux may be drawn below, as in Fig. 2 (p. 959), when it is desired to study particularly the E.M.F.'s in the coils that are shorted or in different circuits. For instance, it is evident that with the flux distribution shown in Fig. 2 there would be no reversing E.M.F. in the sections under short until almost the very end of the short, and the diagram makes it clear how by shifting the middle part forward, that is, by giving lead to the brushes, the forward E.M.F. in one half of the section is reduced, while the counter E.M.F. in the other half is increased at the same time, the terms "forward" and "counter" being here used with reference to the way of the current in the conductors just before the short started.

Any current which comes between the poles is linked with the whole flux, and consequently any excess of current there in one way above that in the other way will cause a magneto-motive force affecting the total number of lines. If the field current be represented by crossed and dotted circles in the "magnetising space" between the poles, as suggested by Mr. Mordey,[1] we can see at once whether it is assisted by the armature current or not. This brings out at once the well-known fact that lead in the direction of the peaked end of the flux wave, the direction required for sparkless collection, causes the armature to exert a demagnetising M.M.F., while a lead in the other way causes an assisting M.M.F. A study of the different examples also shows that there may be at one instant an opposing M.M.F., while at another stage of commutation there may be none, or even an assisting one. It is thus to be expected that the flux through the armature has a periodic variation due to the armature reaction when the armature is carrying a current. The diagrams are all drawn for the case of a dynamo whose brushes have no lead. For a dynamo the peak of the flux curve is on the forward side, the flux being apparently dragged round with the armature. To make them apply to a motor, for which the reverse would be the case, it is only necessary to suppose all the motions and E.M.F.'s to be reversed, while the current and poles remain the same. The E.M.F.'s will then oppose the current.

To make it perfectly clear what this diagram actually means, a row of circles has been drawn in Fig. 1 with their centres on O X and the divisions there as diameters. These are cross-sections of the conductors when the index line of the brushes is at A C, and the marks inside them show the way of the current in them at that instant. A cross represents "down" and a dot "up," while the blanks indicate that the groups are shorted, and not necessarily that there is no current in them. If any other line, such as P Q, be taken as the centre line of the circles, they will show the cross-sections of the conductors with the currents in them when the index line of the brushes is at the position represented by the prolongation of P Q across the commutator at the left.

Another way of looking at the diagram is this. The co-ordinates

[1] *Journ. Inst. E. E.*, vol. xxvi. p. 532. Mordey on "Dynamos."

of any point on the centre line of a sloping space are the position relative to the pole face of the group represented by that space, and the position of the brushes relative to the commutator, as abscissæ and ordinates respectively, on the scales shown diagrammatically at the top and side. A scale of time might be marked along either axis as the motion is uniform, but the vertical one is best for this as there is only one line moving across it.

The following modification may be made. Draw the commutator and sloping diagrams on a strip of paper the same width as that portion of the diagram, and set out the poles and brush on a separate sheet. Make two horizontal slits in the latter just under the poles, a short distance apart, and starting from the face of the brush. Distinguish between the down, up, and shorted places by distinctive colours, or by dots, crosses, and shading, and thread the strip from the back through the lower slot and back by the other, so that only a narrow band of the sloping diagram is visible. A hole should be cut out so as to let enough of the commutator be seen. The narrow band will then show the condition of affairs at one particular instant. By pulling the strip up or down, that at any other instant may be obtained, the conductors appearing to move along the poles and the commutator past the brushes while the strip is in motion.

In many cases it will be found unnecessary to draw in all the sloping lines, but that those bounding the up, down, and shorted spaces will suffice.

End Connections.—The end connections may be drawn in if desired as shown in the first example, the front ones being drawn at the top and the back ones below. It then becomes like an ordinary developed diagram, only the active conductors are represented by the spaces, and they are drawn sloping. When using it in this way the centre lines of the spaces represent the active conductors, but when using it for the current diagram these represent cross-sections of the conductors.

Consequently the poles must be shown behind the sloping diagram for the developed diagram, whereas they must be at the top for the current diagram. To correspond with the ordinary developed diagram, which shows the conditions at some particular instant, the pole edges would have to be sloped parallel to the other lines, but the dotted lines already drawn may stand for them if it is remembered that then different levels in the sloping spaces refer to the positions of the conductor at different instants of time.

Several Layers. Toothed Cores.—When there are two, or more, layers to be represented, we may either represent them by separate diagrams for each, or divide the space between them. The latter is the simplest and best method, if the conductors at the same radius are enclosed between thicker lines and it is remembered that each of them fills the whole space between these lines.

Similarly, when desired, the teeth of slotted cores may be shown in the diagram, so as to reveal exactly the position of the currents, but this is a refinement that is not as a rule necessary.

Example I.—2-Circuit, Singly Re-entrant, 2-Pole, Wave-wound, Drum :—

Number of conductors or groups of conductors $= G = 16$.
Number of segments $= s = 8$.
" circuits $= c = 2$.
" windings $= w = 1$.
" poles $= p = 2$.
Average pitch $= (m\,G \pm c)\,/\,p = \bar{y} = 7$.
where $m = 1$.
Front pitch $= \bar{y} - (n\,G + a)\,/\,p = y_f = 7$.
Back pitch $= \bar{y} + (n\,G + a)\,/\,p = y_b = 7$.
where $n = 0$.
Brush width $= b = 0{\cdot}8$ segments for each of two brushes.
Pole pitch $= \Pi = 8$ groups $= 4$ segments
Pole span $= \sigma = 0{\cdot}75$ of $1\,/\,p$ of circumference $= 135^\circ$.

WINDING TABLE.

F	B		F	B		F	B		F	B		F
	D	U		D	U		D	U		D	U	
a *e*	1 9	8 16	*h* *d*	15 7	6 14	*g* *c*	13 5	4 12	*f* *b*	11 3	2 10	*e* *a*

Since there are but two poles, the brushes are diametrically opposite. There are eight segments, or four per pole, hence diametrically opposite to the centre of *a* there is the centre of *e*. Hence the centres of both these segments are at the same level in the diagram, Fig. 1. The first circuit table is for the brushes on *a* and *e*, the index line of the negative brush being at the centre of *a*, and that of the positive brush at the centre of *e*. The brushes are supposed to be of equal width, and symmetrically set; if this were not the case, the shorts at the two brushes would not start and stop simultaneously as shown in the diagram.

CIRCUIT TABLE. BRUSHES ON *a*, *e*. OX *on Diagram*.

Seg	D	U	D	U	D	U	D	U	Seg
− → *a*	1	8	15	6	13	4	11	2	*e* → +
	10	3	12	5	14	7	16	9	

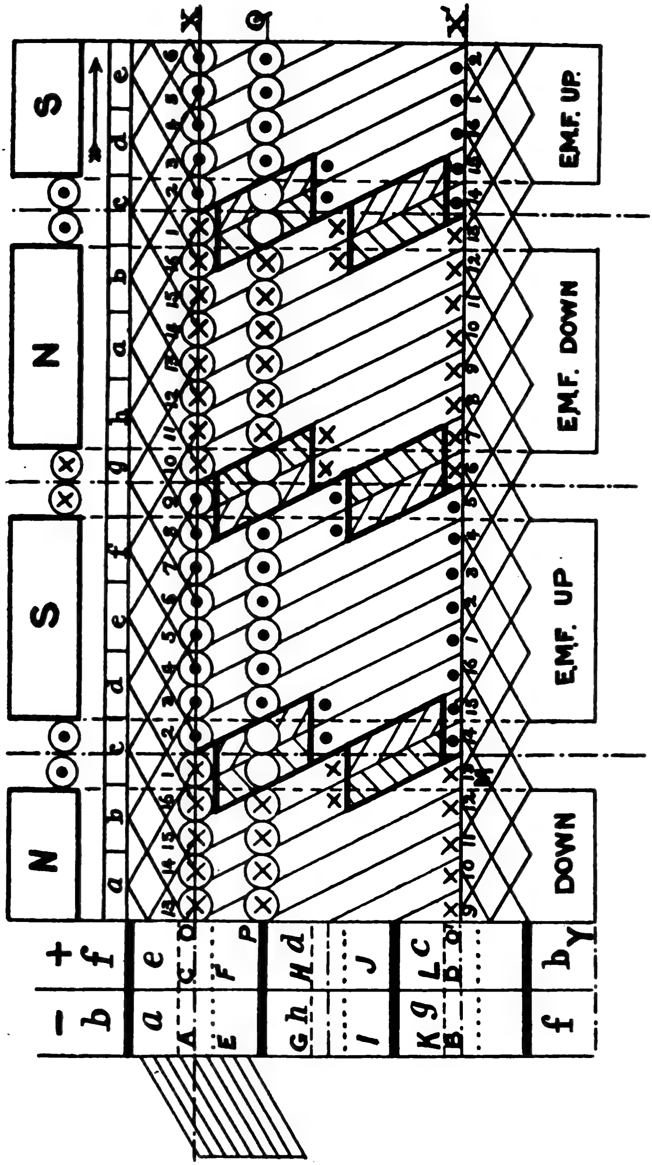


FIG. 1.—Combined Current and Developed Diagram for 2-Circuit, Singly Re-entrant, 2-Pole, Wave-wound, Drum. $G_1 = 16$; $\bar{y} = y_f = y_b = 7$; $b = 0{\cdot}8$.

CIRCUIT TABLE. BRUSHES ON *ha, de* PQ *on Diagram*

	Sh	Seg	D	U	D	U	D	U	Seg	Sh	
	8	*h*	15	6	13	4	11	2	*e*	9	
−	1	*a*	10	3	12	5	14	7	*d*	16	+

A lap winding for the same number of groups, taking $y_b = 7$, and $y_f = -5$, would have given a current diagram with exactly the same features, but the relative position of poles and groups for a given position o. the brushes would have differed considerably from the diagram for the wave winding.

Example II.—Chord Winding. 2-Circuit, Singly Re-entrant, 2-Pole, Lap-wound, Drum :—

$G = 16, \quad s = 8, \quad c = 2, w = 1, p = 2, m = 0, n = 1, a = -8.$
$\bar{y} = (m\,G \pm c)\,/\,p \qquad = 1.$
$y_f = \bar{y} - (n\,G + a)\,/\,p = 1 - 4 = -3.$
$y_b = \bar{y} + (n\,G + a)\,/\,p = 1 + 4 = 5.$
$b = 0{\cdot}8$ segments for each of the two brushes.
$\text{II} = 8$ groups $\qquad = 4$ segments.
$\sigma = 0{\cdot}61$ of $1\,/\,p$ of circumference $= 112\frac{1}{2}^{\circ}$.

WINDING TABLE

F	B			F	B			F	B			F
	D	U		D	U		D	U		D	U	
a	1	6	*b*	3	8	*c*	5	10	*d*	7	12	*e*
e	9	14	*f*	11	16	*g*	13	2	*h*	15	4	*a*

CIRCUIT TABLE. BRUSHES ON *a, e*

	Seg	D	U	D	U	D	U	D	U	Seg	
−	*a*	1	6	3	8	5	10	7	12	*e*	+
		4	15	2	13	16	11	14	9		

CIRCUIT TABLE BRUSHES ON *ha, de*

Sh	Seg	D	U	D	U	D	U	Seg	Sh
4	*a*	1	6	3	8	5	10	*d*	7
− 15	*h*	2	13	16	11	14	9	*e*	12 +

The diagram brings out clearly how the shorts are spread over the pole faces in the case of a chord winding, and how the up and down

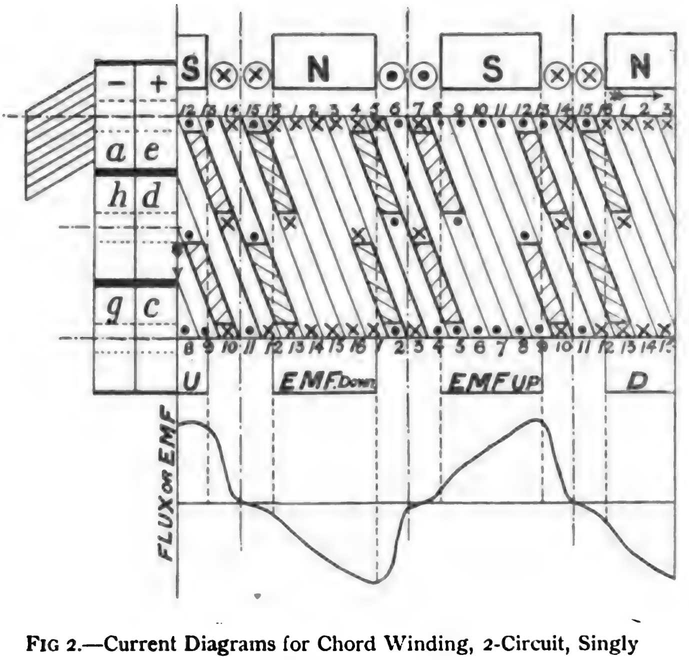


FIG 2.—Current Diagrams for Chord Winding, 2-Circuit, Singly Re-entrant, 2-Pole, Lap-wound, Drum. Two Brushes of Width = 0·8 Segment. G = 16 ; $\bar{y} = 1$; $y_f = -3$; $y_b = 5$.

currents are interspersed between the poles. The chord of the back pitch is equal to the pole span, which is less than in Example I.

Example III.—4-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. 4 Brushes :—

$G = 24,\quad s = 12,\quad c = 4,\ w = 1,\ p = 4,\ m = 1,\ n = 0,\ a = 0.$
$\bar{y} = (m\,G \pm c)/p \quad = 7.$
$y_f = \bar{y} - (n\,G + a)/p = 7.$
$y_b = \bar{y} + (n\,G + a)/p = 7.$
$b = 0{\cdot}8$ segments for each of four brushes.
$\Pi = 6$ groups $= 3$ segments.
$\sigma = 0{\cdot}75$ of $1/p$ of circumference $= 67\tfrac{1}{2}^\circ$.

WINDING TABLE.

F	B		F	B		F	B		F	B		F
	D	U		D	U		D	U		D	U	
a e i	1 9 17	8 16 24	h l d	15 23 7	22 6 14	c g k	5 13 21	12 20 4	j b f	19 3 11	2 10 18	e i a

CIRCUIT TABLE. BRUSHES ON *a, d, g, j*.

Seg	D	U	D	U	D	U	Seg
− a, g	1	8	15	22	5	12	j, d +
	6	23	16	9	2	19	
	13	20	3	10	17	24	
	18	11	4	21	14	7	

CIRCUIT TABLE. BRUSHES ON *la, cd, fg, ij*.

Sh	Seg	D	U	D	U	Seg	Sh
18	a	1	8	15	22	c	5
23	l	16	9	2	19	j	12
6	g	13	20	3	10	i	17
− 11	f	4	21	14	7	d	24 +

There are three segments per pole. Hence when the index line of the first negative brush is at the centre of *a*, those of the other brushes are at the centres of *d*, *g*, and *j*, these being the third, sixth, and ninth letters after *a*. It will be observed from the circuit table that the shorts take place only through the connection between two brushes of the same polarity. Consequently, these must of necessity be joined together if sparkless collection is to be possible.

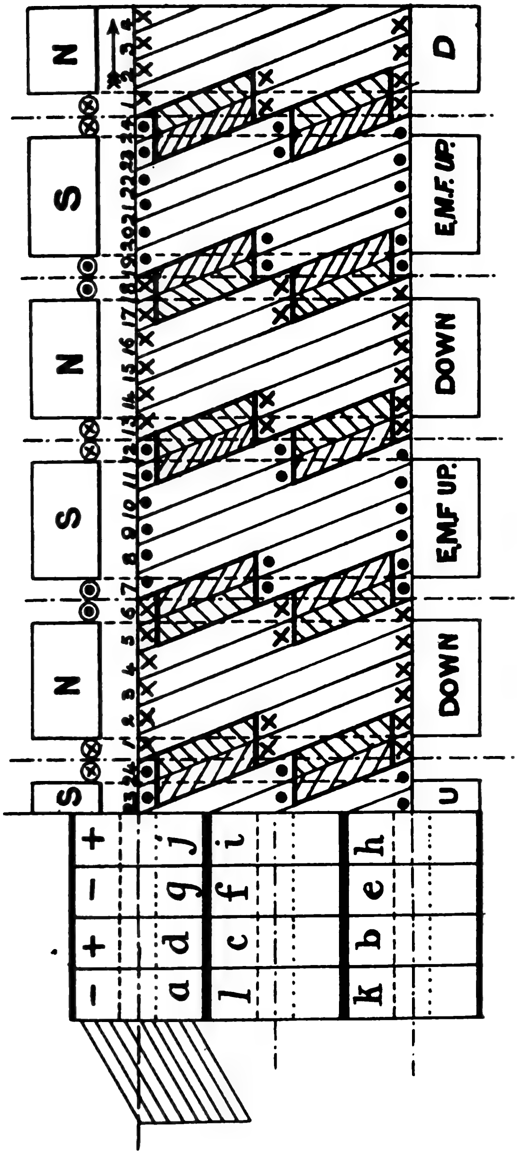
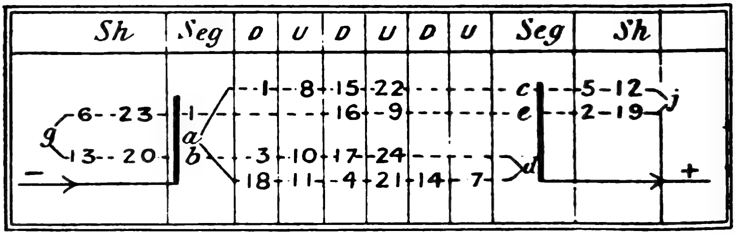


FIG. 3.—Current Diagram for 4-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. With Four Brushes.
$G = 24$; $\mathfrak{y} = y_f = y_b = 7$; $b = 0·8$.

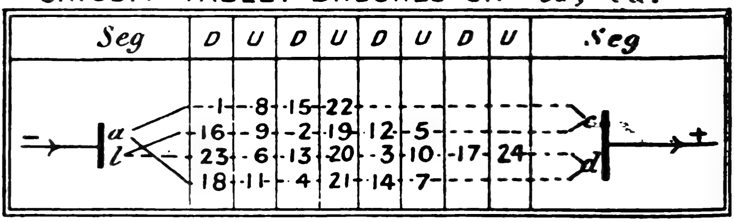
A lap winding with $y_f = -5$, and $y_b = 7$, would give the same distribution of current, but the relative position of the poles and numbers at any particular instant would be different. The shorts would also take place through the tips of the brushes.

Example IV.—4-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. 2 Brushes:—This is the same winding as in Example III., but there are only two brushes instead of four. In order that a short may be possible, the brushes must be wider than one segment plus two insulations. The width chosen is $b = 1{\cdot}6$ segment, or twice that in Example III. The winding table, and other particulars, are the same as before. The brushes are 90°, or three segments apart.

CIRCUIT TABLE BRUSHES ON *lab, cde.*



CIRCUIT TABLE. BRUSHES ON *la, cd.*



The current diagram shows us that the shorts are no longer symmetrically disposed about the poles. At the place which is between the brushes, the shorts are spread out as in a chord winding, while at the adjacent two, although close together, one of them is behind the centre line dividing the poles, and the other ahead of it. The fourth one, which is furthest from the brushes, is of the same character as before.

The circuit tables reveal the great dissymmetry of the circuits themselves. In the first table, one circuit has only two groups, while another has six. This will be to some extent counterbalanced by the fact the groups in the small circuit are in a most effective position, whereas some of those of the long circuit are almost idle. With a larger number of sections, although the absolute dissymmetry remains the same for a given ratio of brush width to segment width, it will be proportionally less. With a given relation between these, there will

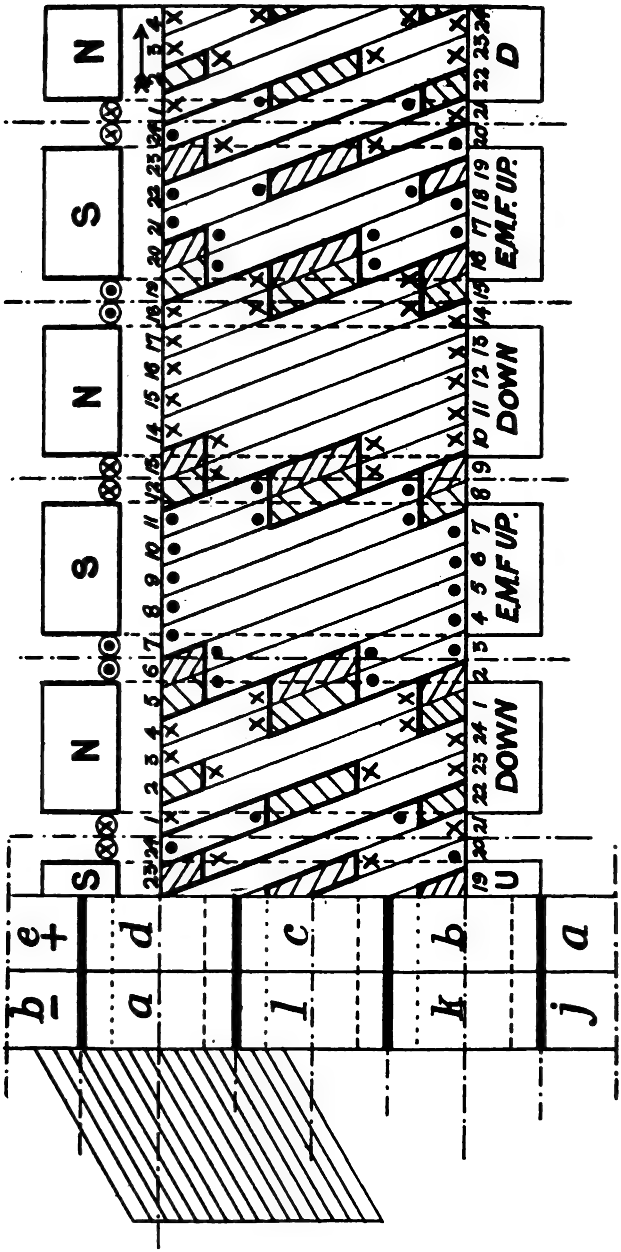


FIG. 4.—Current Diagram for 4-Circuit, Singly Re-entrant, Wave-wound, Drum. With Two Brushes.

G = 24; $\mathfrak{y} = y = y_b = 7$; $b = 1{\cdot}6$.

always be positions in which one circuit will have four groups less than some other, and if the brushes are not exactly set, so that one short starts, or stops, before another, there will be positions where the difference is six groups. With a constant angle of contact of the brushes the proportional dissymmetry remains the same for any number of sections. These considerations indicate that it is preferable to employ four brushes with this type of winding.

Example V.—2-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. 4 Brushes:—

$G=30, \quad s=15, \quad c=2, w=1, p=4, m=1, n=0, a=0.$
$\bar{y}=(mG \pm c)/p \quad =7.$
$y_f=\bar{y}-(nG+a)/p=7.$
$y_b=\bar{y}+(nG+a)/p=7.$
$b=0{\cdot}8$ segments for each of four brushes.
$\Pi=7\frac{1}{2}$ groups $\quad =3\frac{3}{4}$ segments.
$\sigma=0{\cdot}75$ of $1\ p$ of circumference $-67\frac{1}{2}°$.

WINDING TABLE

F	B		F	B		F	B		F	B		F	B		F
	D	U		D	U		D	U		D	U		D	U	
a	1	8	h	15	22	o	29	6	g	13	20	n	27	4	f
f	11	18	m	25	2	e	9	16	l	23	30	d	7	14	k
k	21	28	c	5	12	j	19	26	b	3	10	i	17	24	a

CIRCUIT TABLE BRUSHES ON *a, de hi lm.*

Se	Sh	Se	D	U	D	U	D	U	D	U	D	U	Se	Sh	Se
	1---8	h	15	22	29	6	13	20	27	4	11	18			m
a													e	2--25 9--16	l
	24--17	i	10	3	26	19	12	5	28	21	14	7	d	30-23	

CIRCUIT TABLE BRUSHES ON *a, de, hi, l.*

Se	Sh	Se	D	U	D	U	D	U	D	U	D	U	D	U	D	U	Se	Sh	Se
	1---8	h	15	22	29	6	13	20	27	4	11	18	25	2	e	9-16	
a																	l
	24-17	i	10	3	26	19	12	5	28	21	14	7	-	-	d	30-23	

The shorts are symmetrical here with reference to the poles, and during most of the time the circuits are also symmetrical. But there will be a short time during which one circuit has two groups more than the other, as shown in the second table. This assumes that one short is finished just before another is started. If the reverse of this is true, then there will be one section (two groups) in each circuit less than

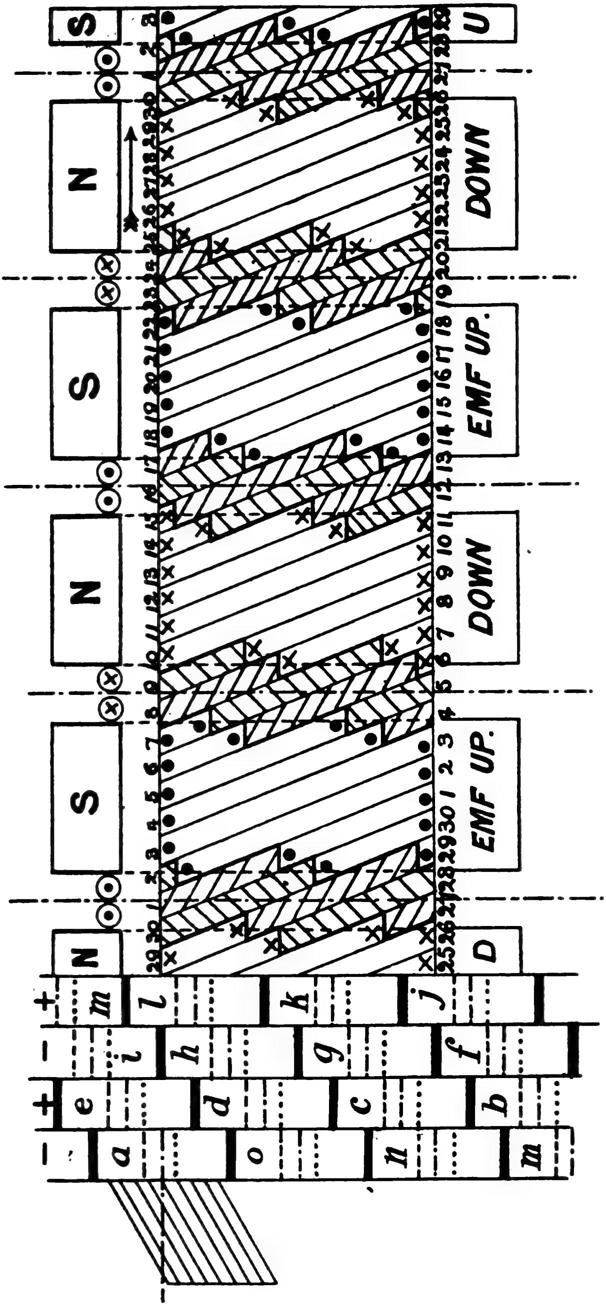


Fig. 5.—Current Diagram for 2-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. With Four Brushes.

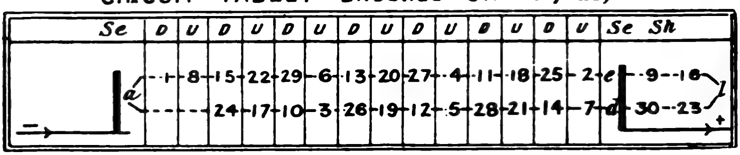
$G = 30$; $\bar{y} = y_f = y_b = 7$; $b = 0{\cdot}8$.

shown in the second circuit table, and there will be six groups shorted at each end the same as at the right hand of the first circuit table. The diagram shows the shorts starting at the same instant as another is stopped, due to the fact that the brush width is $\frac{3}{4}$ of the segment pitch plus one insulation. In that case, the unsymmetrical arrangement can only last for an instant during the change. The effect of other brush widths can be easily studied from the tables and diagram.

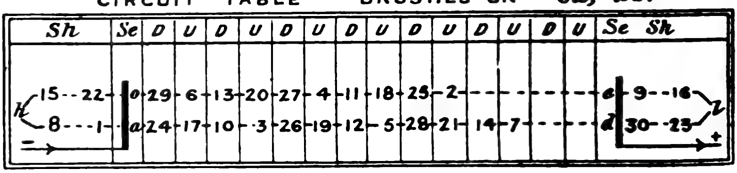
In this example there are $3\frac{3}{4}$ segments per pole. Hence the index lines for successive brushes are this distance apart on the commutator. This explains how the position of the different rows has been obtained in the diagram. The different letters at the several brushes are easiest obtained after the left-hand portion of the diagram has been drawn.

Example VI.—2-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. 2 Brushes:—This is the same winding as the last, but only two brushes of the same width as before, and 90° apart, are used. The winding table and other particulars are as before. The minimum width of brush is a little more than the thickness of the insulation, just as in the case when four brushes are employed.

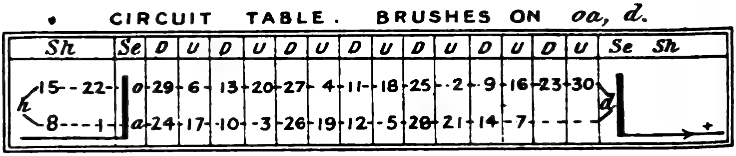
CIRCUIT TABLE. BRUSHES ON *a, de,*



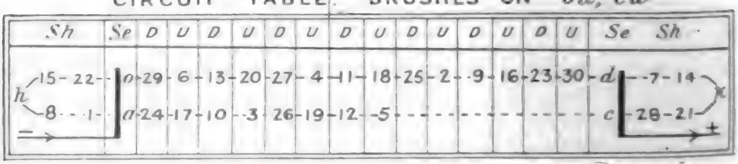
CIRCUIT TABLE BRUSHES ON *oa, de.*



CIRCUIT TABLE. BRUSHES ON *oa, d.*



CIRCUIT TABLE. BRUSHES ON *oa, cd*



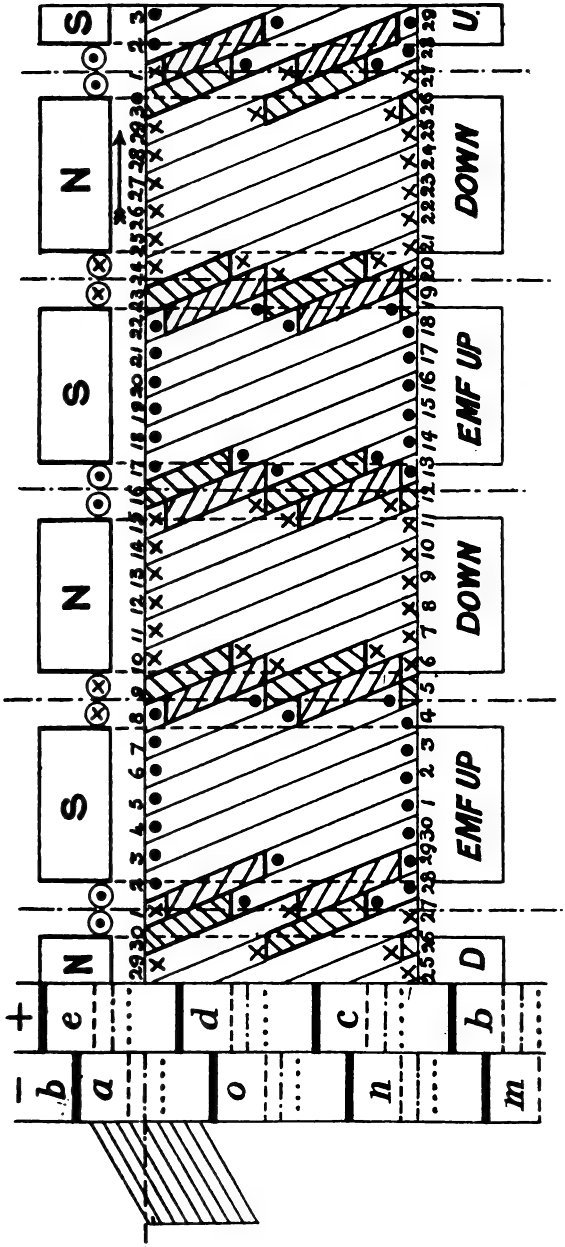


FIG. 6.—Current Diagram for 2-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. With Two Brushes.

$G = 30$; $y = 8$; $y_f = 7$; $y_b = 7$; $b = 0{\cdot}8$.

As this winding is one in common use, a complete set of circuit tables has been made, showing the circuits for all the different stages of commutation, starting with that at the top. The next stage after that represented in the fourth table is to break contact with *a*. This takes place at almost the same instant as the previous one, viz., making contact with *c*, in the diagram, but for the tables it is assumed to take place later. After both these have taken place, the state of affairs again becomes the same as in the first table, but with different numbers and letters. If the brushes are assumed to be a little narrower than this, as in the previous example, the fourth table would be for the brushes on *o*, *d*, and there would then be no shorts. Those at the left hand of the third table would be thrown into the lower circuit, before those at the other end of the fourth table were taken out, and so the lower circuit would be longer than the upper by two groups, instead of being shorter by six. There would thus be less dissymmetry.

We see that with only two brushes the circuits are never symmetrical, whereas with four brushes they are only different for a little while between two shorts, or at the end of a short. Also, the distribution of the shorts is unsymmetrical with two brushes, but they do not last so long, owing to the fact that with four brushes, when a section gets away from one brush it is still shorted by the other. The greatest distance by which the shorts project over the active region is the same whether there are four or two brushes of the same width, but each of the four brushes might be made narrower than the two single ones, and then the spread of the shorts over the poles would be less for the greater number of brushes. The substance of the remarks made in connection with Example IV. will also apply to this one.

Example VII.—6-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum:—

$G = 38,\quad s = 19,\quad c = 6,\ w = 1,\ p = 4,\ m = 1,\ n = 0,\ a = 4.$

$\bar{y} = (m\,G \pm c)/p \quad = 8.$

$y_f = \bar{y} - (n\,G + a)/p = 8 - 1 = 7.$

$y_b = \bar{y} + (n\,G + a)/p = 8 + 1 = 9.$

$b = 0{\cdot}8$ segments for each of four brushes.

$\Pi = 9\tfrac{1}{2}$ groups $\quad = 4\tfrac{3}{4}$ segments.

$\sigma = 0{\cdot}75$ of $1/p$ of circumference $= 67\tfrac{1}{2}°$.

WINDING TABLE

F	B		F	B		F	B		F	B		F	B		F
	D	U		D	U		D	U		D	U		D	U	
a	1	10	*i*	17	26	*q*	33	4	*f*	11	20	*n*	27	36	*c*
c	5	14	*k*	21	30	*s*	37	8	*h*	15	24	*p*	31	2	*e*
e	9	18	*m*	25	34	*b*	3	12	*j*	19	28	*r*	35	6	*g*
g	13	22	*o*	29	38	*d*	7	16	*l*	23	32	*a*			

The next step is like the first, but the short is on the left, and one line higher up. If the brushes are a trifle wider, the old short does not

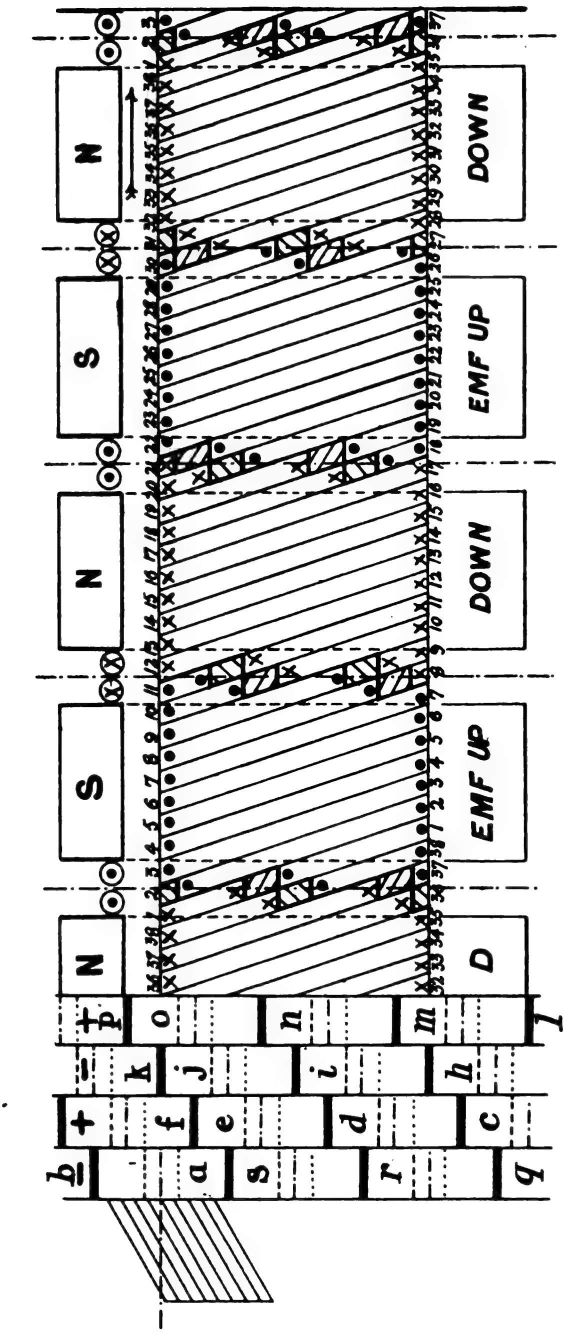
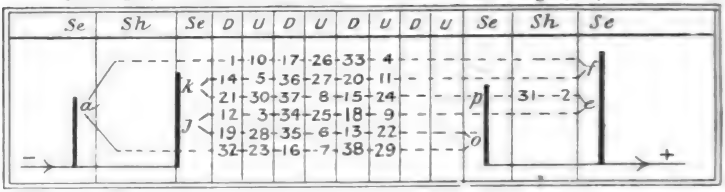


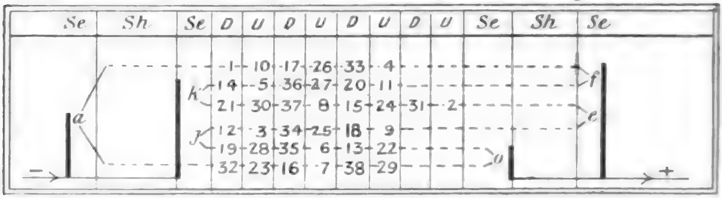
FIG. 7.—Current Diagram for 6-Circuit, Singly Re-entrant, 4-Pole, Wave-wound, Drum. With Four Brushes.

$G = 38$; $y = 8$; $y_f = 7$; $y_b = 9$; $b = 0{\cdot}8$.

CIRCUIT TABLE. BRUSHES ON *a, ef, jk, op.*



CIRCUIT TABLE. BRUSHES ON *a, ef, jk, o,*



disappear before the new one comes. The result is that the third circuit will have two groups less than the others, instead of two groups more, in the transition stage between the first table and the next with only one short. This winding could also be run with only two brushes, provided each is made wide enough to touch four segments at once, but the want of symmetry so produced would be even worse than in Example IV. or VI.

Parshall & Hobart[1] would call this a "2-Circuit, Singly Re-entrant, Triple-wound, 4-Pole, Drum," presumably because it has three times the minimum number of circuits possible with a wave-winding, and because it can be run with two brushes. Similarly they term the winding of Examples III. and IV. a "2-Circuit, Singly Re-entrant, Double-wound, 4-Pole, Drum."

Application to Alternators.—The same principles may be applied to the study of armature reaction in alternators at any instant. Instead of the lines for the commutator at the left hand, set there, about a vertical axis, the wave forms for the current and E.M.F., taking account of their proper phase relations. By projecting along from the zero current points on the wave, the positions of the conductors when the current gets reversed are obtained, but now all in one phase will reverse at once. Also, the positions of all the conductors for any instant, and the current in them at that instant, are at once obtained by drawing a horizontal line at the proper level.

The effects of phase displacement, of wave form, and of distribution of winding can thus be very clearly shown. If there are several phases they may all be treated in the same way, the proper waves being all drawn together in proper relation, the current in any group being of course obtained from the wave for that phase.

In the case of uni-slot windings especially, the teeth form a large proportion of the whole. They should therefore be represented in the diagram as well as the conductors, so as to get a proper idea of the actual distribution of the current.

[1] *Armature Windings.* (London: Electrician Publishing Co.).

JOURNAL

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The Three Hundred and Seventy-fifth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 20th, 1902—Mr. W. E. LANGDON, President, in the Chair.

The minutes of the Ordinary General Meeting held on March 13th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Arthur Henry Foyster.

From the class of Associates to that of Members—

Bertram Hopkinson.

From the class of Students to that of Associates—

Cyril Renton Heron.
Percy G. Moore.
John Ernest Schofield.
Maurice Arthur Wood.

Dr. C. V. Drysdale and Mr. A. Schneider were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Macmillan & Co., and to the

Building Fund from Messrs. B. Balaji, R. J. Browne, and F. A. Glover, to whom the thanks of the meeting were duly accorded.

The report of Major-General Webber's Reply to the discussion on his paper, and of the vote of thanks to the authors of the three papers on "Electrical Shocks," that followed here, was published in part 156 of the Journal, p. 813.

PROBLEMS OF ELECTRIC RAILWAYS.

By J. SWINBURNE and W. R. COOPER.

Argument.—Problem of short lines different from main lines. Paramount importance of acceleration and retardation in urban lines. Owing to capital invested in building urban lines quick service pays at great electrical cost. The present system derived from tramways unsuitable for railways. Improved constant pressure system more economical. Series constant current system still better, because there is no waste in resistance and most of the kinetic energy is returned in braking. Substations and transformations also avoided. Three-phase constant pressure inferior to direct current in efficiency and convenience. Simple alternating current inferior to improved direct current. Dynamotor system expensive and inefficient. Electric traction not ready for main lines. Main-line problem entirely different. Acceleration unimportant. Difficulties in distribution. Constant pressure direct current costly in distribution. Constant current series saves substations and simple in distribution and working. Constant pressure alternating simplest of all in distribution, but troublesome and inefficient on the train. Alternating and three-phase both prohibit varying speed.

Conclusions.—Present tramway traction not suitable for urban and suburban railways, but electric equipment superior to steam and necessary for immediate future development on urban and suburban traffic. Main-line problem not yet ready for serious treatment.

INTRODUCTION.

The electric railway has now been with us for a decade, and it has recently been developing rapidly in America and on the Continent. The first steam railway in this country to change is going to be converted to electric haulage as soon as the work can be carried out; and there is great activity in the direction of building "Tubes."

In all cases it has been taken for granted that the constant potential system which is employed for street tramways

is correct for railways; and the development is going rather in the direction of turning railways into big high-speed tramways. In many cases it has been considered that the railway of the future is to be a sort of glorified tramway with single, and perhaps double, cars running at frequent intervals, or at sight.

One of the most dangerous results of the present development is that engineers are equipping individual railways without considering the effect on railways as a whole. The steam railways of the country are now all connected; and rolling stock of any one company runs over practically the whole system of British railways. The only thing that is necessary to secure this convenience is uniformity of gauge and sufficient height. The Great Western has now come into line with the other railways. Many engineers think that the Great Western had the best gauge, as it was chosen specially for railways, while the ordinary gauge is simply the survival of the stage-coach measurement. If electric railways become general, as there is no doubt they will very soon, uniformity in gauge is not enough; we ought to have uniformity of electric supply, both as to pressure and current, and as to nature of supply, such as direct, alternating, or three-phase. If alternating or three-phase is used, the frequency should be standardised also.

It is proposed in this paper to urge for consideration the claims of series distribution of power for railways, especially for short lines, such as the Tube and suburban types. Its use for main lines will also be discussed, as it would be greatly against its use on short lines if it were useless on long railway systems. We will also mention shortly some other systems which may merit discussion.

We are so accustomed to thinking of trains as going, that we may be rather apt to forget the importance of starting and stopping. In a Tube railway, for example, the starting is the vital question. It is always easy to stop, as that is merely a question of brakes.

The steam locomotive is an admirable machine for its purpose. It can give a great torque at starting without undue waste of energy; and it can reduce the torque at full speed if desired, and run economically. This machine, however, is being replaced by the constant pressure motor, which can be made to give any torque desired, certainly;

but which gives it only at great expense of power at starting.

Urban Lines.

Urban lines are characterised by a very varying load, the largest number of passengers being carried between the hours of say 8 to 10 in the morning and 5 to 7 in the evening, the trains being comparatively empty during a great part of the day. There is no doubt traffic can be created, and the greater the facilities the greater will be the traffic. It is therefore essential that there should be a frequent service; and not only frequent, but sufficiently rapid to make it worth people's while to walk to and from a station rather than to take another means of travelling which is nearer at hand. Successful traffic is always the result of competition. If a frequent service of this kind is fairly patronised during the hours of low load, then during the hours of heavy load the line is almost certain to be unable to cope satisfactorily with the traffic. This is seen in the case of the Central London Railway, where there is much crowding just before and after business hours. It may be said that a little overcrowding of this kind does not matter, but that is not the case. It is certainly not of much importance to those who are able to use the terminal stations; but it is very inconvenient to people who join at intermediate points, and who, rather than attempt to gain admission to overcrowded trains, will use some slower means of locomotion on account of greater comfort. Under these conditions a line may get a bad name along part of its route during the hours of heavy load, and may practically be turning away passengers. This is evidently bad policy if it can possibly be avoided, because the capital expenditure on urban lines is very heavy and they can pay a satisfactory dividend only if worked to a high capacity. The way in which traffic may be created was shown very well on the Hartford-New Britain line (U.S.A.), on which it increased 400 per cent. during the three summer months on conversion of the line to electric working with a reduction in the fare from 23 cents to 10 cents.

The capacity of a line with a given mean speed of running may be raised by increasing the number of

trains, but this method is limited owing to the distance headway between trains, and is bad owing to the fact that the rolling stock, power-station, and staff are all increased, and that capital so involved may be idle during a large part of the day. The better course, and in some cases the only course, is to raise the mean speed. This enables a more frequent service to be run without increasing the number of trains or the staff; there is, however, an increased load on the generating station, not only on account of the quicker service, but generally also on account of the greater speed. But in many cases this is only a small objection, because the cost of the generating and distributing plant is a small part of the total, and the cost of fuel is only one, and not necessarily the most important, of a number of items which go to make up running costs. Fuel is sometimes spoken of as if it were the controlling factor in these costs, but that, of course, is quite a mistake in railways of this kind, if an increase of capacity has to be considered on account of overcrowding.

Consider, for example, the results obtained on the Central London Railway. Here the capital to December 31 of last year was £3,681,313, and the train mileage for the year was 1,243,730, so that 5 per cent. on this capital amounts to 35·5d. per train-mile, which represents the difference that should exist between receipts and expenditure to provide this dividend on the train-mileage quoted. A figure of this kind has not yet been reached. At present the mean speed is about 22 km. (14 miles) per hour, or 15½ miles per hour including stops, the length of the line being 9·2 km. (5¾ miles) with 13 stations. The average stop at stations is about 15 seconds. It is noticeable that the time taken for the train to come to rest after the locomotive reaches the station is very considerable, being about 15 to 20 seconds. The average headway is from 2½ to 2¾ minutes at the busiest time.

Let us now consider the effect of running trains half as fast again during the heaviest hours of traffic, so that the time of headway is reduced. We will assume that the effect of this is to increase the traffic, and therefore the receipts, by 20 per cent. The increase in car-mileage would not be so great if the service were uniform all day, because the increased speed will be maintained only during the

TABLE I.

Financial Results of the Central London Railway.

	Six Months to December 31, 1901.			Modification by Increased Traffic.	
Train Mileage	614,517			737,420	
	Total.		Per Train Mile.	Total.	Per Train Mile.
Maintenance of Way, Works and Stations.	£	£	d.	£	d.
Maintenance of Way... ... Wages	2,173				
Maintenance of Way... ... Materials	699				
Repairs of Structure, Stations, etc.... ...	976				
Salaries, Office Expenses, and General Superintendence	332	4,180	1·634d.	4,500	1·46d.
Locomotive and Generating Power.					
Coal and Coke	13,664				
Wages	9,830				
Oil, Water, Gas and Stores	1,895				
Repairs and Renewals ... Wages	3,839				
Repairs and Renewals ... Materials	1,914				
Salaries, Office Expenses, and General Superintendence	1,519	32,661	12·760d.	36,800	11·98d.
Repairs and Renewals of Cars.					
Salaries, Office Expenses, and General Superintendence	100				
Cars ... ... Wages	1,463				
Cars ... ... Materials	789				
Lifts ... ... Wages	1,717				
Lifts ... ... Materials	769	4,838	1·890d.	5,500	1·79d.
Traffic Expenses.					
Salaries and Wages—Stations and Service	19,153				
Fuel, Lighting, Water, and General Stores	7,220				
Electric Lifts—Wages and Materials ...	5,187				
Miscellaneous Expenses	3,121	34,681	13·550d.	35,000	11·40d.
General Charges.					
Directors	1,250				
Salaries of Secretary, General Manager, and Clerks	2,756				
Other charges	2,510	6,516	2·546d.	6,516	2·13d.
Rents, Rates, and Taxes		6,535	2·553d.	6,535	2·13d.
Miscellaneous Items...		1,132	0·442d.	1,132	0·37d.
TOTAL		90,543	35·375d.	95,983	31·23d.
Revenue		168,359	65·80d.	202,000	65·74d.
Excess of Revenue over Expenditure ...		77,816	30·425d.	106,017	34·50d.
Percentage of Total Expenditure to Revenue...	53·8 per cent.			47·5 per cent.	
Percentage of Profit to Capital for the Half-year	4·3 "			5·76 "	

heaviest hours, say four hours per day, and will be unnecessary on Sundays; but as the number of trains on the line is greater during the busy hours, we will take 20 per cent. as the increase in train mileage also.

The accounts of the last six months, to December 31, are given in the accompanying table in the first three columns, whilst in the last two are given the accounts as modified by the assumed increase in traffic. In calculating these modified figures certain items may be considered as constant—for example, salaries. Thus the maintenance of way will not increase by as much as 20 per cent., the increase being chiefly in wages and materials. The locomotive and generating expenses would increase 20 per cent. if the speed remained constant, but as the speed is higher we will assume the fuel to be increased 25 per cent., making an allowance for lifts, or by £3,400, and about £750 to be added on account of oil, water, etc., and repairs, bringing the total to £36,800. The figure for repairs is increased to £5,500. The increase in the traffic expenses would be small, being chiefly in connection with the lifts, and therefore the sum of £34,681 is increased only to £35,000. The remaining items may be regarded as constant. We therefore arrive at a total of £95,983, or 31·23d. per train-mile. The revenue, allowing 20 per cent. on receipts, becomes, say, £202,000, or 65·74d. per train-mile. The expenditure is therefore reduced from 53·8 per cent. to 47·5 per cent. of the receipts, and the percentage of profit to capital for the half-year is increased from 4·3 per cent. to 5·76.

It may be objected that this high-speed service cannot be run without adding to the generating plant and distributing system throughout. But if a considerable sum, say £85,000, be spent for this purpose, and the wages be increased by, say, £1,000 for the six months, the percentage of profit to capital for the half-year is still as high as 5·6 per cent. per annum. The result is, therefore, very appreciable, even if additional plant is necessary. Under certain conditions, as will be shown later, the load on the generating station is not necessarily very much increased.

Let us now consider how a high mean speed is best attained. A journey may be divided into periods of acceleration, of running at more or less constant speed, of

braking and of rest at stations. Taking the last item first, it is only necessary to say that the periods of rest are very important when the distance between stations is short, and they become increasingly so as the mean speed is raised. In the case of the Central London Railway, the trains stop on the average about 15 seconds at each station, which amounts to 10 per cent. of the total time. If people are in some way informed what the next station is going to be, a stop of 10 seconds is generally long enough, especially if the cars are arranged, as on the Metropolitan of Paris, so that a door at one end is used for entering the car and one at the other end for leaving.

The periods of acceleration, steady running, and braking are so closely connected together that we shall consider them all under the head of acceleration.

Acceleration.

Variation of Acceleration and Maximum Speed.—As far as economy of time is concerned, the higher the acceleration and retardation, and the higher the speed of steady running, the more satisfactory is the service. But the extent to which the acceleration can be increased is limited in three ways, (1) by discomfort reaching high acceleration may cause the passengers; (2) by increase in cost, not merely in energy but also in generating plant and the distributing system; and (3) by slipping, which can generally be avoided in practice. The maximum speed, as distinct from acceleration, is also limited by cost, not on account of the energy required to maintain the speed, which may be comparatively unimportant, but on account of the consumption in accelerating up to that speed. Owing to the time of steady running being so short, the energy used in acceleration is far more important than that required during the remainder of the run.

With regard to discomfort to passengers caused by acceleration, it is worth while to consider the retardations at present used for braking. The following table, to which a column has been added expressing the retardations in metres per second per second, is reproduced from a paper by Mr. W. B. Potter.[1]

[1] *Street Railway Journal*, vol. 13, p. 670, October, 1897.

TABLE II.

Retardations in Use on Railways.

Railway Company.	Remarks.	No. of Cars.	Weight of Train in net Tons.	Grade.	Type of Brake.	Speed in Miles per Hour on Application of Brakes.	Distance Stopping in Feet.	Time Stopping in Seconds.	Average Retardation per Second in Miles per Hour.	Average Retardation in Metres.	Equivalent Braking Effort in Pounds per net Ton.
Metropolitan Elevated	Service	2	44	L	Straight Air.	19	181	13	1·45	0·65	133
Lake Street Elevated	Service	2	44	L	Autom. Air.	25	293	16	1·56	0·7	142
Alley Elevated	Service	3	72	L	Autom. Air.	31	522	23	1·35	0·6	125
Illinois Central	Service	4	116	L	Autom. Air.	40	1,086	37	1·08	0·48	98
Manhattan Elevated...	Service	4	95	L	Vacuum.	22	387	24	·92	0·41	84
Cleveland, Painesville & Eastern	Service	1	20	L	Electric.	40	585	20	2·0	0·89	183
Cleveland, Painesville & Eastern	Emergency	1	20	L	Electric.	30	220	10	3·0	1·34	275
Lorain & Cleveland	Emergency	1	23	L	Electric.	45	461	14	3·21	1·44	295
Schenectady Street Railway ...	Service	1	9	L	Electric.	23	135	8	2·88	1·28	263

In a report by Sir Frederick Bramwell and Mr. E. A. Cowper (1881) on Continuous Brakes, various retardations were recorded, that for working conditions giving a mean retardation of 1·05 metres per second per second, or if two seconds be allowed for the time elapsing between the signal being given and the application of brakes, a retardation of 1·2 metres per second per second.

High retardations are, of course, usual enough, but it is otherwise with acceleration. This is due to the use of the steam locomotive which does not give a large torque if built for high speed; and even though suburban locomotives are built for large torque and low speeds, yet the acceleration is comparatively low. In the accompanying table, (Table III.) which has been taken from Mr. W. B. Potter's paper already mentioned, are given the accelerations used on several American railways, showing the values during the first 10, 20, 30, and 40 seconds after starting. Columns have been added to this giving the accelerations in metres per second per second.

From these figures it is seen that the retardation in braking on steam railroads is much higher than the acceleration in starting. In the case of electric railways the acceleration is often a good deal higher than with steam, and this change has resulted in a very much improved service on many lines. For example, on the Nantasket Beach line (U.S.A.), a distance of 10·6 miles with sixteen stops is run in twenty-six minutes, or at a mean speed of 24½ miles an hour—a result that would be impossible with steam locomotives. The stations are about 0·6 mile apart, the maximum speed about 40 miles per hour, and the mean energy for the whole trip about 83 watt hours per ton-mile (180 kj. per tonne-kilometre). It will be noticed that this speed is very much higher than any we are accustomed to on urban railways in this country. As already mentioned, the mean speed on the Central London Railway is only about 14 miles per hour. On the City and South London Railway, Mr. P. V. McMahon[1] prefers an acceleration and retardation of 1·46 feet (0·445 metres) per sec.^{2} and a maximum speed of 16·25 miles (26 kilometres) per hour with a distance of 2,700 feet between stations, giving speed conditions closely resembling those found on steam rail-

[1] *Journal of the Institution of Electrical Engineers*, vol. 28, p. 558. 1899.

	30 Seconds.				40 Seconds.		
	Average Acceleration in metres per sec.²	Speed miles per hour.	Distance run feet.	Average Acceleration per sec. in miles per hour.	Average Acceleration in metres per sec.²	Speed miles per hour.	Distance run feet.
Ietr	0·45	30	660	·87	0·39	34·8	1,020
ake	0·345	23·2	510	·69	0·31	27·6	870
lley	0·36	24	540	·715	0·32	28·6	840
llin	0·305	20·5	450	·64	0·285	25·6	750
Ian	0·26	17·5	386	·52	0·23	21	615
pe	—	—	—	—	—	—	—
pe	—	—	—	—	—	—	—
pe	—	—	—	—	—	—	—

roads. But it would be impossible to compete against modern electric tramways at such a low speed.

Generally speaking, there is still a considerable difference between the accelerations and retardations used in electric traction. No discomfort is felt through rapid braking, and therefore there is no reason why an acceleration as high as 1 metre per second per second, or even higher, should not be used from the point of view of comfort. As far as convenience to passengers goes, it is not so much the acceleration, as the time rate of change of the acceleration, that is important. When a train is pulled up quickly there is generally a rapid change of retardation at the moment of stopping, but as the passengers are as a rule sitting down, this rapid change is not objectionable. In the case of acceleration, on the other hand, people are frequently standing, not having had time to find their seats. If an acceleration of, say, 0·8 metre per second per second is applied, a man standing vertically must lean $4\frac{1}{2}^{\circ}$ in the direction in which the train is going if he is to be in equilibrium. This is a sudden change. It should be clearly understood, however, that there is a difference between a train starting with a jerk, and the acceleration starting suddenly. The train starts perfectly smoothly even if the acceleration suddenly jumps to its full value and stays there, but a man standing feels a sudden change and has to allow for it. People that are standing should receive warning by a gradual increase of the acceleration. It is, therefore, more important that the acceleration should begin gradually than that there should be a gradual decrease of retardation at stopping.

The effect of varying the acceleration, retardation and maximum speed are best shown by working out an actual case.

We therefore assume a Tube railway with stations 0·75 kilometre apart, and 17 stations, the line being 12 kilometres long. The stations would not in practice be equidistant; but for simplicity we will assume that they are so. The generating station may be taken at one end, as such a tube would be run from a suburb into a city. In a paper written by one of us for the Manchester Section of this Institution a similar tube was to some extent worked out on these lines, with a smaller acceleration, namely, 0·7 m/sec.^{2}. We

will take the same weight of train, namely 100 tonnes, or 100,000 kilogrammes, and for convenience we will express the results in the decimal system.

Railway people measure distances in miles and chains and acceleration in miles per hour per second, and electrical engineers throw aside the chief advantages of their scientific metric units by using Board of Trade units, watt-hours per ton mile, horse-power, horse-power hour, and so on. If electrical engineers would only try, merely as an experiment, to use their own units, they would realise their beautiful simplicity. In dealing with such quantities as acceleration and kinetic energy they are specially convenient. It is also a pity to make our work unintelligible in other countries, and to make it more difficult for us to understand the work of Continental engineers, who are by

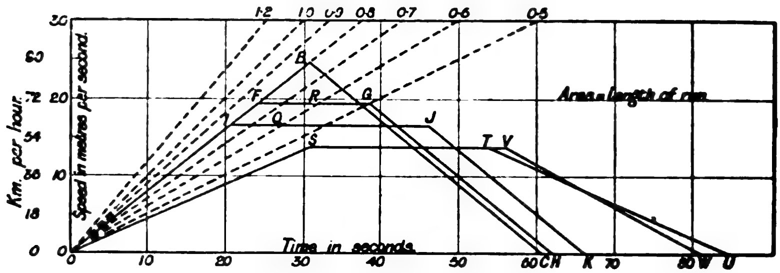


FIG. 1.

no means idle in electrical traction. We have therefore used English units when quoting or dealing with quoted matter, but have otherwise worked in metric measure, placing English equivalents in brackets where convenient.

Fig. 1 shows graphically the relations of some of the quantities we must deal with. The co-ordinates are speed and time. Constant acceleration is then an inclined straight line, and constant speed a horizontal straight line. The area of a curve or polyhedron is then the distance. The areas of all the curves should thus be equal to 750 metres.

The line O B represents uniform acceleration at 0·8 m/sec.². At B the time is 30·4 seconds, and the train is half-way. If it is retarded at 0·8 m/sec.² its motion is shown by the line B C, arriving at zero speed at 60·8 seconds. The maximum speed is 88 km. (55 miles) per

hour. If the acceleration is stopped at a maximum speed of 70, the trace is O F G H. The difference is only a second and a half, out of a minute, or out of 70 seconds including the time of stopping, which may be taken as 10 seconds. Taking the kinetic energy at B (*i.e.*, the energy used in acceleration) as 1, that along the trace F G is 0·633. Thus 58 per cent. more energy is used if the maximum speed is raised from 70 km. per hour to the highest value possible under these conditions (88 km.), or there is a saving in energy of 37 per cent. if the lower maximum speed is used, with a loss of only about 2 per cent. in the time. If the maximum speed is further reduced to 60 km. per hour, the trace O I J K is obtained which takes 4 seconds more, but requires only 46·4 per cent. of the

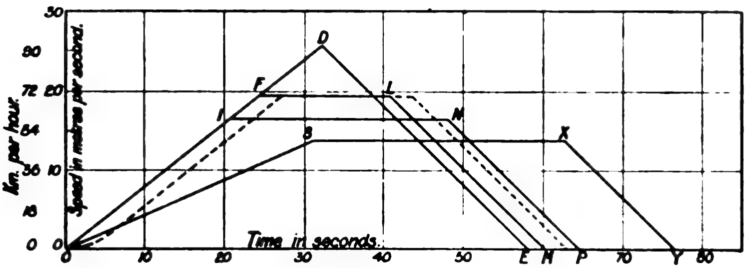


FIG. 2.

energy taken by the trace with the peak B consisting wholly of acceleration and retardation.

In Fig. 2 there is a trace O D E shown. This is for an acceleration of 0·8 and a retardation of 1; and needs 58·23 seconds. The maximum speed is 93 km. per hour, needing 13·5 per cent. more energy, and saving about 2 seconds. It is probably admissible to brake a little faster than to start up, and if electrical braking is used with the motors working at full load, the braking is more rapid than the acceleration in about this proportion. We will therefore adopt a retardation of approximately 1 instead of 0·8. O F L M and O I N P are the corresponding traces for maximum speeds of 70 and 60 km. per hour. There is obviously less saving of time in these cases, and neither the acceleration or retardation is quite so important.

In the diagram Fig. 1, there are several dotted lines

representing different accelerations. The line 0·6, for example, cuts the line of 60 km. per hour maximum speed at Q, at 27·7 seconds. I Q is thus 7 seconds. If the retardation is also reduced from 0·8 to 0·6, the total time is increased 7 seconds; if the retardation is not altered, the increase of time is ½ I Q or 3½ seconds. With a higher maximum speed the loss of time is greater, for instance F R.

Another trace O S T U is shown on Fig. 1. This is for an acceleration of 0·4 (1·3 ft.) per second per second, and is for the purpose of comparison with the more usual practice of to-day. The retardation T U is at 0·4 also, but V W is at 0·5 to allow for electrical breaking with the same motors. X Y (Fig. 2) is for retardation of 1, for instance with air brakes.

In practice it is impossible to run a train according to such a trace as O B C, consisting entirely of acceleration and retardation, because a certain time must be allowed for manipulation and errors of judgment. In practice also trains do not run at constant speed. They are always accelerating if current is on, and if they are coasting there is retardation. Consequently the periods which we have called periods of running at constant speed are really represented by inclined rather than horizontal lines, though in comparison with the rates we are considering they are practically horizontal.

The traces in Figs. 1 and 2 are drawn on the assumption that the acceleration reaches its full value at once. If the acceleration is raised gradually so as to give warning to the passengers, a trace is obtained like the dotted lines in Fig. 2, showing that there is a considerable loss of time. As already explained, it is not necessary to introduce a corresponding gradual decrease of retardation in stopping, and therefore loss of time need be occasioned only in starting.

The effect of varying the quantities we have been considering, is shown in a different way by Figs. 3 and 4. Fig. 3 shows the effect of varying the acceleration with a given maximum speed, each curve applying to one value of the maximum. Fig. 4 shows the effect of varying the maximum speed with a given acceleration, each curve applying to one value of the acceleration. In every case the retardation in braking is 1·0 metre, except where the curves are dotted, indicating that the retardation is then 20 per cent. higher than the acceleration. It is seen by Fig. 3 that the higher

the maximum speed, the greater is the effect of varying the acceleration, and by Fig. 4 that the higher the acceleration, the greater the effect of varying the maximum speed. As the retardation with low accelerations is frequently not as

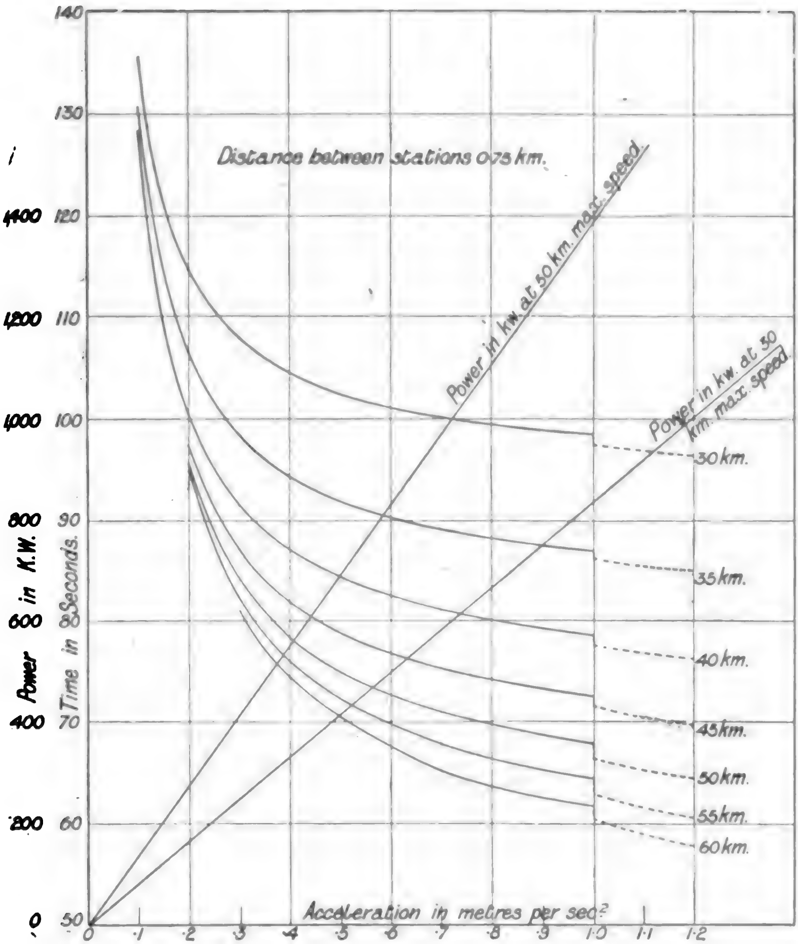


FIG. 3.—Effect of Varying the Acceleration with a given Maximum Speed.

high as 1·0 metre, the effect may be even more marked than is shown by these figures.

Energy and Power required for High Acceleration.—It is well known that, for a given time between stations, the energy required by a train is less the higher the accelera-

tion, because the maximum speed is diminished. The problem which we are considering, however, is more general, namely, What effect has a decrease in the time between stations upon the energy consumed and the power required?

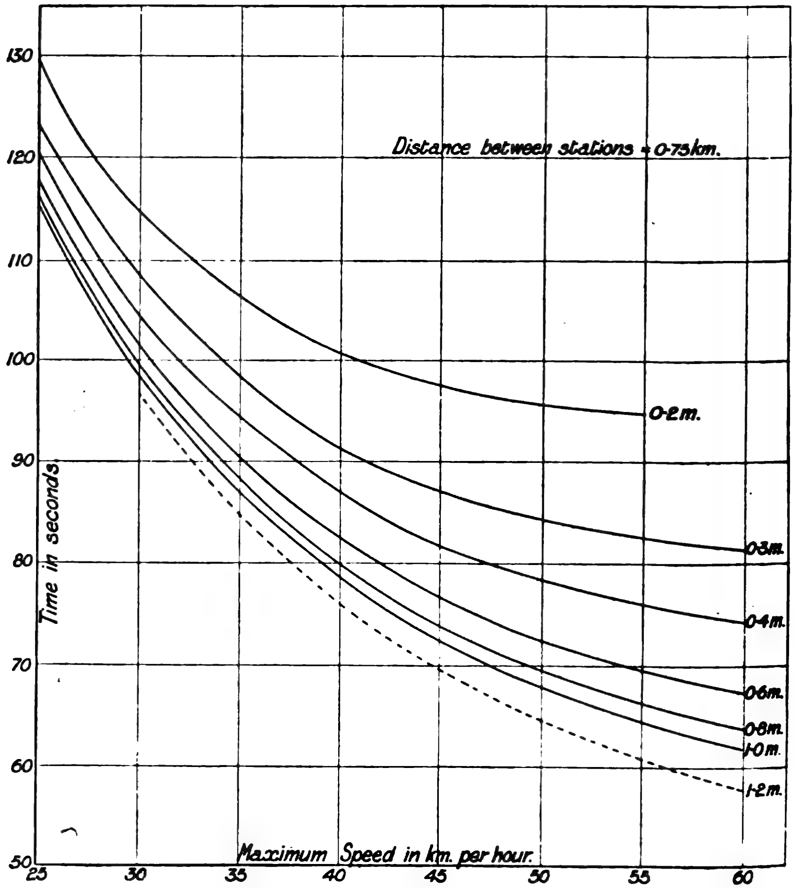


FIG. 4.—Effect of Varying the Maximum Speed with a given Acceleration.

With a given maximum speed, assuming that coasting is adopted after this speed is reached, the energy is independent of the acceleration, the maximum kinetic energy of the train being by hypothesis constant. But if the maximum speed is increased, the energy used varies as the square of

the maximum speed, so that the increase is rapid. This in itself, apart from the generating station, would not be important on an urban line where traffic could be created by a high-speed service.

The maximum power, on the other hand, varies directly as the acceleration for a given maximum speed, and directly as the maximum speed for a given acceleration; or, generally, the instantaneous power varies as the product of the acceleration into the speed. In Fig. 3 is also shown graphically the result of increasing the maximum speed from 30 km. (18·7 miles) per hour to 50 km. (31·2 miles). The energy used in accelerating at the lower speed is 3,500 kj. (0·975 B.T.U.). Assuming that the remainder of the run is effected by coasting and braking, this is at the rate of 46 kj. per tonne kilometre (20·8 watt-hours per ton mile) supplied to the train (*i.e.*, excluding losses due to motors, controllers, etc.). With the higher maximum speed the energy used is 9,700 kj., or at the rate of 130 kj. per tonne kilometre (57·5 watt-hours per ton mile). If the conditions are changed from 30 km. and an acceleration of 0·4 metre per sec.^{2} to 50 km. and an acceleration of 1·0 metre per sec.^{2}, the time is reduced from 104 seconds to 68, or a saving of 36·4 per cent. But the maximum power which is applied to the train is increased from 330 kw. to 1,390 kw.

Such powers are, of course, inadmissible, not only on account of the extent to which it would necessitate increasing the generating plant and distributing system, but also because the motors on the rolling stock would have to be much heavier. The load is also momentary, but this would not cause any difficulty with a frequent service, for which the total load would be fairly steady. Since the power is constant if the acceleration varies inversely as the speed, economy in power would be effected by allowing the acceleration to diminish in the usual way after a certain time, instead of keeping it constant. The speed-curve then would not rise so rapidly, after say, half-speed had been reached; but the time so lost would be small and would be readily made up if the top speed is allowed to exceed the assumed maximum, the only disadvantage being that rather more energy is consumed as the maximum speed is higher.

The method of saving energy by having stations on gradients leading up to them is of great value, though it can

be applied only to a limited extent. The energy saved depends on the vertical distance the train can descend, but in order that the gradient should considerably reduce the power required, it should be so arranged as to be effective when the speed is becoming high if the acceleration is constant, *i.e.*, during the second half of the time of acceleration, when there is the greatest demand for power. If the acceleration is not constant, then the gradients should be arranged to have the greatest effect when the product of speed into acceleration is a maximum. This can be arranged with low acceleration, and effects a large saving; but since the gradient can only be started outside a station, the greater part of the acceleration in the case of high acceleration is completed before the train is fully on the gradient, and the percentage saving is less. Moreover, it is only possible to construct the permanent way in this manner in the case of new lines, as it would generally be difficult and costly to make such an alteration on existing railways.

Two methods present themselves of economising energy per train-mile when the traffic is light. Either the maximum speed may be reduced to, say, one-half, and the trains run at greater time headway, or shorter trains may be run. Since the energy varies as the square of the speed and only as the first power of the weight of the train, more energy is saved by the first method than the second, but this necessitates arranging the motors so that they will run economically at half-speed. The second method is better from the point of view of creating traffic, as the speed is maintained, and it has the advantage of reduced wear and tear; it is particularly suited to the multiple unit system in which the motor power is in proportion to the length of the train.

The only way in which a very large saving of energy and power can be effected is by means of electric braking and return of energy to the line. A very high power in accelerating may in any case be avoided by diminishing the acceleration as the speed increases, as already stated; but the energy used is still considerably increased by using a high acceleration, and also the size of the generating plant, this being at least in proportion to the mean energy required. The value of electric braking will be best seen by the examples which follow; in which

its application to various parallel systems and the series constant-current system are discussed at some length. We shall, no doubt, be accused of taking a specially high acceleration because it shows the series system to the best advantage; and that, it will be said, is the object of this paper. However that may be, the important question is how are such accelerations to be obtained economically. There is no doubt that they are of value and will become general fairly soon. We shall also consider the application of the series system to main lines in which high acceleration is not so important.

In the cases considered, we have assumed accelerations approaching high retardations in value. A high retardation is, of course, easily obtained without slipping, because all the wheels and all the weight are brought into action. The highest accelerations, however, may not be obtainable from a locomotive on account of the comparatively small amount of weight brought into play, though in tube railways in particular the state of the rails is unusually favourable to adhesion. Multiple unit systems, however, afford an easy solution of this difficulty, and have other advantages as well.

We have also assumed, in the examples which have been given, that the tractive force required for running a train at constant speed is negligible compared with the force necessary for acceleration. If the resistance is 0·045 (10 lbs. per ton), the equivalent retardation is only 0·044 metre per sec.^{2}, which does not materially affect the results on open lines. But as shown by Mr. P. V. McMahon,[1] the tractive force in single-track tunnels rises very rapidly with the speed, so that three times the given value, or even more, may be reached at the highest speeds we have taken. This appears to be a slight objection to the single-track form of tunnel.

The practical value of high acceleration has been shown very clearly by recent tests on the Liverpool Overhead Railway, particulars of which have been kindly supplied by the engineer, Mr. S. B. Cottrell. The total length of the line is 10·5 km. (6½ miles), with seventeen stations. Up to the present this distance has been run in thirty-two minutes, or at the rate of about 20 kilometres (12½ miles) per hour.

[1] *Journal of the Institution of Electrical Engineers*, 1899, vol. 28, p. 540.

Tests with new rolling stock have shown that this time can be reduced to 20·4 minutes, the time at stations remaining eleven seconds as before. The total weight of the train, including passengers, during the trial run was 46·3 tons, the total carrying capacity of the train being 154 passengers. The energy required increased from 250 kj. per tonne km. (110 watt-hours per ton mile) to 310 kj. per tonne km. (137 watt-hours per ton mile) or 6·35 units per train-mile. The total cost of producing and transmitting this energy would be about 3d. per train-mile. In Table IV. is given a summary of the results obtained.

TABLE IV.

RESULTS ON THE LIVERPOOL OVERHEAD RAILWAY.

	Old System.	Accelerated Service.
Mean speed	12½ miles (20 km.)	19¼ miles (31 km.)
No. of stops	16	16
Mean time at stations	11 seconds	11 seconds
Mean distance between stations	729 yards (666 m.)	729 yards
Watt-hours per ton mile	110	137
Acceleration	1·6 feet (0·44 m.) per sec.^{2}	3 feet (0·91 m.) per sec.^{2}
Retardation	3 feet (0·91 m.) per sec.^{2}	4·8 feet (1·26 m.) per sec.^{2}

An average acceleration of at least 3 feet (0·91 m.) can be relied on, a maximum of over 4 feet (1·22 m.) having been recorded. Fig. 5 shows graphically the results obtained on a trial run between Brunswick Dock and Toxteth Dock on the Liverpool Overhead Railway. The gradients of the line are given on the distance diagram. There is only one curve which is at the beginning of the third section.

The train used in these trials consisted of two motor-cars and one trailer, each of the motor-cars being equipped with two 75 kw. motors. A point of interest in connection with the motors (which are made by the English Electric

Manufacturing Company of Preston) is that they reached the unusually high efficiency of 93 per cent. at the full load of 75 kw., and that their weight is 4,200 lbs. or only 42 lbs. per H.P. (25·4 kg. per kw.), which is a point of great importance in keeping down the dead weight of the train. With the motors, two in parallel, two in series, the current frequently rises to 700 or 800 amperes. The motors will carry 80 amperes continuously without over-heating, but they carry three to five times that amount during periods of high accelerations.

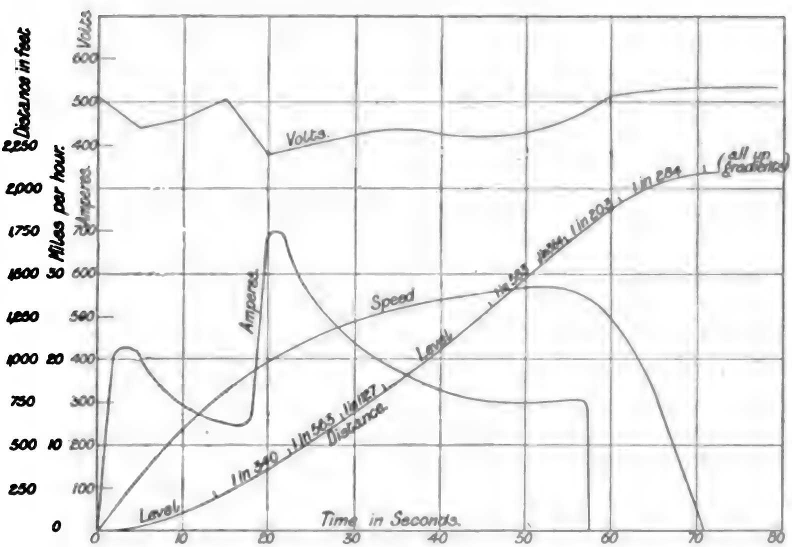


Fig. 5.—Running Test between Brunswick Dock and Toxteth Dock on the Liverpool Overhead Railway.

Fig. 6 shows the value of the retardation used in braking, the test being made at Brunswick Dock.

We will now consider various systems and their suitability for urban railways.

Pressure.

As to the pressure, 500 volts has the advantage of being safe; but from the shareholders', and therefore in the long run from the passengers' point of view, it is more expensive in every way than a higher pressure. It is probable that the exigencies of transport will accustom us

very soon to treating a railway as a dangerous thing. We do not prohibit the use of locomotives because they kill you if you get run over; people know that and keep out of the way. In the same way, when people understand that electric wires are dangerous at high pressure they will touch them at their peril. We will therefore assume a train pressure of 2,000 volts.

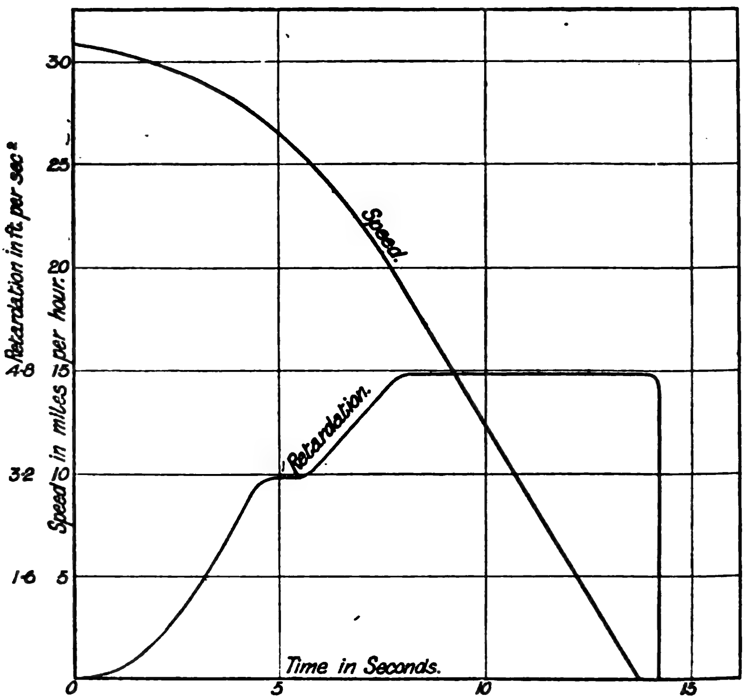


FIG. 6.—Braking Test at Brunswick Dock, Liverpool Overhead Railway.

Constant Pressure Urban Railway.

We may now go into a comparison of the systems by taking special examples. Merely to get something definite to go upon we may take 0·8 m. (2·62 ft.) per sec.^{2} as acceleration for the rapid trains we hope to travel in in the immediate future, and 0·4 m. (1·3 ft.) per sec.^{2} to get our comparisons into line with present-day practice.

A little preliminary examination of the behaviour of motors is here advisable. The present practice is to use

series motors in pairs on constant-pressure circuits, generally at 500 volts. Suppose such motors are used for a train we wish to design to follow the trace O F L M approximately (Fig. 2). As the maximum speed is 19·45 m./sec. or 70 km. (43·75 miles) per hour, we might wind the motors to take their full current and give their full volts at that speed. To take round numbers for simplicity, we may suppose at the speed corresponding to 70 km./sec. the pressure is 500 volts and the normal current 3,200 amperes, 1,600 in each motor in parallel. It will also be assumed that the controller is such that the current is kept at *exactly* 3,200 amperes, and that

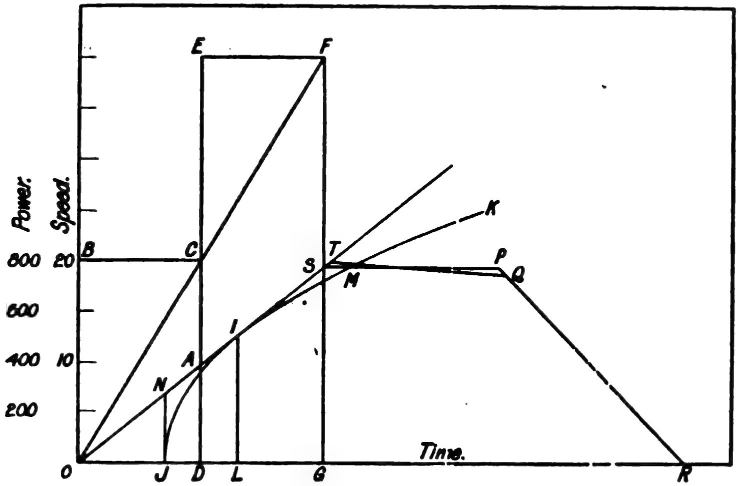


FIG. 7.

the resistance of the motors is negligible. In Fig. 7, x is time and y is speed (in metres per second) as in Fig. 1, but y is also power, so as to give two traces on one plane.

Case I.—At O the train starts with the motors in series, and 500 volts and 1,600 amperes, or 800 kilowatts. As time goes on, when half-speed time is reached, at A all the resistance is switched out, and the motors are giving 500 volts back-pressure (neglecting the resistance of the motors). O B C D then represents the energy used in getting to half-speed. Of this the triangle O C D has been converted into kinetic energy, and O B C has been wasted in the resistances.

The motors are now put in parallel, taking 3,200 amperes

or 1,600 kilowatts. The area D E F G represents the energy taken, and of this C E F is wasted on resistance, the rest being used. The total waste in starting is thus $\frac{1}{3}$. If the motors had not been put in series for the first half of the acceleration, the energy would have been twice D E F G and the waste $\frac{1}{2}$, demanding 25 per cent. more energy.

We can imagine the driver to coast along S P, or a path close to it, till he reaches the line P R, when he brakes. He would probably leave the motors on a little after S, going up, say to T, and then coasting down T G, but we can for simplicity imagine he has got to P. Assume braking with series machines possible for the moment. The machines would be put in series, giving 1,000 volts, and resistance would be inserted to keep the current 1,600 amperes. The motors acting as dynamos then return 1,600 amperes at 500 volts for half the braking time. That is an area equal to O B C D, and is half the kinetic energy of the train. The motors cannot brake below half-speed, so further braking is done by friction. The total efficiency is thus 0·5.

Case II.—The starting may be made more efficient by choosing a lower speed for cutting out the last of the resistance. Thus, if the controller is not altered at S the train would go on accelerating, though not uniformly, and this acceleration would be economical, as there would be no resistance waste. The acceleration would depend on the characteristic of the motor. For simplicity, let us imagine hypothetical motors without resistance, and with such permeable fields that the pressure varies as the speed and as the current. We would then probably arrange the normal speed of the motors, that is to say, the speed at which they give 500 volts with 1,600 amperes at say L I. The acceleration curve of such motors on constant pressure can be shown to be a cubic J I K. The curve touches the line of uniform acceleration. The part J I K starts with an infinite current, and the current is above our normal until I is reached. After that, the acceleration and current fall off; but throughout the curve the efficiency is 1, as there is no resistance waste. If O L is $\frac{2}{3}$ of O G, the energy up to that point will be $\frac{4}{9}$ of the total energy due to the speed G F, and this energy will again have been obtained at an efficiency of $\frac{2}{3}$. The

other $\frac{5}{9}$ will be obtained at an efficiency of 1, with a slight loss of time, as the curve I K sheers off the line O F. If the kinetic energy of full speed be called 1, the first method described takes in $1\frac{1}{2}$, wasting $\frac{1}{2}$ and then returns $\frac{1}{2}$, wasting the other $\frac{1}{2}$. The intake is $1\frac{1}{2}$, the return $\frac{1}{2}$, and the loss 1. The latter arrangement takes in $\frac{2}{3}$ up to I, wasting $\frac{2}{9}$, and then takes in from I to M $\frac{5}{9}$, wasting none. It thus takes in, altogether, $\frac{11}{9}$ and wastes only $\frac{2}{9}$, so that the efficiency is so far 0·82. But we come to a difficulty in braking. Braking with these hypothetical dynamos would be impossible, as they would be unstable. For series machines to act as dynamos on a resistance and back pressure combined, they must depart radically from our hypothetical machines. We must therefore forego any return of energy by braking. Our total intake is thus $\frac{11}{9}$ or 1·22 instead of 1·5, but we return nothing, so we keep 1·22 instead of 1. Having regard to the size of the station, it is probably better to use 1·22 returning nothing than to draw 1·5 and return 0·5. Moreover, braking even with specially designed series machines would be very troublesome, requiring complicated gear. Very accurate and gradual adjustment of the resistances would be also necessary, and the system is not at all practical. The motors would also wear more at their commutators. Our return and efficiencies are also hypothetical, and too high.

The nominal object of this paper is mainly to compare series working with existing systems, and in order to do so properly we must be fair to the present systems and give them every chance we can. Electrical return braking is not used now, but neither are the large accelerations we contemplate. With large accelerations and high speeds on short journeys the return of energy by braking becomes of much greater importance. The real object of this paper is not to advocate any system in particular to the exclusion of any other.

Case III.—Shunt machines have been used for returning energy by braking at constant speed. Three-phase motors work as brakes in the same way, but merely as a convenient method of braking, not because the energy is valuable. This practice has only been in connection with constant speed, and in the case of three-phase is clearly only possible under that condition.

But we may wind shunt machines, with weak fields, to have their normal current, and normal fields at I in Fig. 7.

The treatment from O to I is then the same as in the case of series machines. At I, the machines are left on with no resistances. If left alone the trace would then start off on a horizontal line. But if the field is weakened by a rheostat controlled by the main current, the trace will follow the curve to M with the same results as to efficiency. As the field varies with the current the machine is as sparkless as an unsaturated series motor, and perhaps more sparkless than those now in use.

On braking the motors are quite stable, and the braking trace is practically the reverse of the trace O I M. Again, taking the kinetic energy of full speed as 1, the motors return $\frac{5}{9}$ down the curved part corresponding to I M, and from I to N the return is $\frac{2}{9}$. From N to O it is, of course, zero. On this system the motors take in $\frac{11}{9}$, or 1·2, and return $\frac{7}{9}$, or 0·77, using $\frac{4}{9}$, or 0·44.

Case IV.—If a series motor is placed on a constant-current circuit, it requires no resistance for starting, and it is brought to rest by merely short-circuiting. When this short-circuit is opened the constant current passes in the machine, which starts up with constant torque and maintains this torque at all speeds so long as the current in the fields is not altered by shunting. Thus the usual form of controller is not required, and there are no controller losses. Consequently if urban railways could be run by series motors on constant current, one of the most serious causes of loss would be avoided. Moreover, if the armature of such a motor is reversed when running, it returns energy to the line; and since the current remains the same, the torque, on braking, is the same as for acceleration (neglecting losses); and therefore retardation is the same, and is maintained up to the point of stopping. Thus the motors take in 1, the waste is 0 and the return is 1.

We may compare the results so far obtained. Taking the kinetic energy as 1, we have:—

	Taken.	Waste.	Return.
I. Series with electric braking ...	1·5 ...	1 ...	0·5
II. Series without „ „ ...	1·2 ...	1·2 ...	0
III. Shunt with „ „ ...	1·2 ...	0·4 ...	0·7
IV. Series constant current system ...	1 ...	0 ...	1

We will, therefore, select III. for our typical constant-pressure system, at least for high speeds on urban lines, in spite of its not being in use, as we thus give the constant-pressure system at least a very fair representation. It must be borne in mind that we have so far been discussing hypothetical motors without resistance; in practice nothing like these results can be obtained.

Constant Pressure Rapid Urban Train.

Case V.—We may now work out a more practical case of an urban constant-pressure equipment to fit the trace O F L M of Fig. 2 approximately. We will assume that the motors are shunt, and lose 4 per cent. in their fields, 4 per cent. in their armatures, and 8 per cent. by mechanical losses, making an efficiency of 84 per cent. at their normal speed and current.

Taking the train at 100 tonnes (98·5 tons) and the acceleration at 0·8 m/sec.^{2} the pull is 8,000 megadynes (8,150 kilos, or 18,000 lbs.). At the normal, or I of Fig. 7, we will take O to I, 15 seconds as a convenient round number, the corresponding velocity being 12 m/sec. (43 km. or 27 miles per hour). The power is then $8{,}000 \times 1{,}200 \times 10^{-4}$ kw., or 960 kw. At 2,000 volts this means 480 amperes. The motors must therefore give a torque on the axles equivalent to 960 kw. at 12 m/sec. (43 km. per hour). No allowance has yet been made for train resistance. We may take 250 kg. (5·6 lbs. per ton), or, to make round numbers, 250 megadynes (255 kg., or 565 lbs.) as the pull needed to overcome train resistance. This figure is so small in comparison with the acceleration pull, that we may take it as constant without appreciable error. At a speed of 12 m/sec., 250 megadynes are equivalent to 30 kw. The motors must therefore deliver 990 kw. to the axles at 12 m/sec. As the motor efficiency is 84 per cent., 1,178 kw. must be drawn from the line, or 589 amperes at 2,000 volts. For 7½ seconds, therefore, the motors take in 589 kw., and for 7½ seconds 1,178; and then we reach the point I, having taken in 13,250 kilojoules (nearly 3·7 units). From I to full speed namely, 19·45 m/sec., means an increase of kinetic energy, which, with the traction, amounts to 12,000 kj. We may take this, at 0·84 efficiency, as 14,400 kj. (3·9 units). To

go along the flat part of the trace by turning on the motors for a moment and coasting will take, say, 500 kj. Our total intake is thus 28,150 kj. (7·83 B.T.U.), and the kinetic energy is 18,900 kj.

On braking down to I the motors return approximately 9,600 kj. (2·67 units). During half the rest of the retardation the return is 2,940 (0·82 unit), making a total of 12,540 (3·5 units). So, taking the kinetic energy as 1, we take in $1\frac{1}{2}$, waste $\frac{5}{6}$ and return $\frac{2}{3}$, which is approximately the same as our hypothetical but impossible Case I.

Constant-current Rapid Urban Train.

As far as we are aware the series constant-current system for traction was first proposed by Fleeming Jenkin, and was used in early days for electric tramways, but on

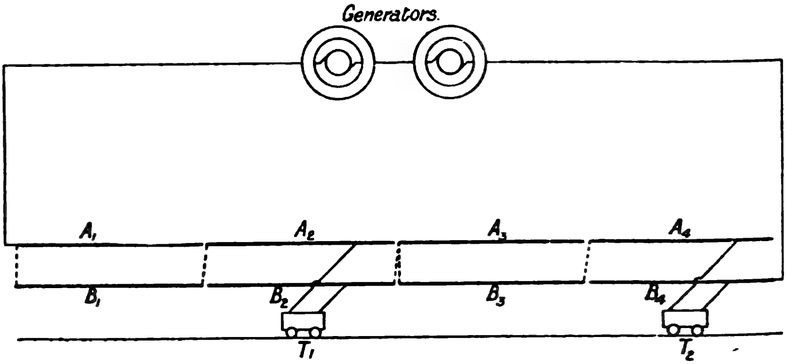


FIG. 8.—Series Constant Current System.

account of its complication in this case it was abandoned. M. Blondel more recently suggested the system for electric railways, but nothing seems to have come of the proposal.[1]

As the system is not well known, we will give a brief description of it. Two conductors divided into sections are necessary throughout the line. In Fig. 8, A_1, A_2, A_3, A_4 are sections of one of these conductors, and B_1, B_2, B_3, B_4 are sections of the other. At the end of each section there must be a switch to connect to the next section; and if a section has no train upon it, it must be short-circuited, as indicated by the dotted connections. The figure shows trains T_1 and T_2 on sections A_2 and A_4. The circuit is therefore along B_4 until the motors of the train T_2 are

[1] *Electrical World*, vol. 31, pp. 21–23, 1898.

reached. For the remainder of the section the circuit is along A_4, then through the short-circuited section A_3—B_3, through the motors of the train T_1 on the section A_2—B_2, and finally through the short-circuited section A_1—B_1 to the generating station.

Advantages.—The merits of the system may be summarised shortly :—

1. The efficiency as regards loss of energy by controllers and return of energy to the line is high.

2. The all-over efficiency is high, because there is no transformation between the dynamos in the generating station and the motors on the train.

3. The torque is constant, and may be so maintained as long as desired.

4. The torque may be varied at will by shunting the field, or by varying the position of the brushes.

5. The control is simple, because the current is constant and need not be large. Therefore the controlling gear is light and inexpensive. In order to get more variation of torque than may be convenient by the methods just mentioned, two motors may be used, these being placed in series at starting, and one of the motors short-circuited after a time; finally, the motors may be run in parallel, thus giving 1, $\frac{1}{2}$, and $\frac{1}{4}$ as the relative values of the torque.

6. There is a marked economy of copper under certain conditions.

7. Collection of current should be simpler than with the usual parallel systems as it is smaller.

8. High pressure in transmission is likely to be more easy to handle than by alternating current, as the dielectric is not subjected to an alternating stress. The highest pressure which M. Thury has used on his transmission lines appears to have been 22,000 volts, but there is no reason why higher should not be used.

Disadvantages.—1. The greatest difficulty is the necessity for careful insulation of the motors. With stationary motors this is a comparatively simple matter, the foundation being suitably insulated, and the shaft being insulated from anything which it is driving by a Raffard coupling or other means. The insulation would not be so simple on a locomotive, but the difficulty could probably be overcome if the constant-current system shows enough advantages.

2. Double contacts and double conductors are of course necessary, no earth return being available. These are no doubt undesirable, but they do not form a vital objection.

3. The loss due to the resistance of the line is constant, and therefore the percentage loss increases with light load; but since traction systems seldom work light, this point is not important in the case of urban railways. In main lines, it can generally be kept low with a little care.

Case VI.—If we follow the same trace O F L M on a series system at constant current, the motors are taking a maximum power at F. The maximum power is a serious consideration, as it determines the size of the plant. We will therefore run with two motors in series up to 12 m/sec. and then run with a single motor, at half acceleration: or we may follow exactly the same curve as our shunt machines, by weakening our fields by shunting them, so that they take constant power. As the current is constant, that means constant pressure, of 2,000 volts. Taking the motors and gear as having 84 per cent. efficiency, at 12 m/sec. (43 km. or 27 miles per hour) we get 2,000 volts and 589 amperes. From start to 12 m/sec. the motors take in 9,550 kj. (2·63 units). From 12 to 19·45 m/sec. they take 14,400 (4 units) and along the top 500, making 24,450 (6·8 units). On braking, the motor returns 9,600 (2·57 units) down to 12 m/sec., and after that returns 6,000 (1·67 units) more braking to a stop; making 15,600 (4·33 units) returned. We thus have 1·3 taken in, 0·49 wasted, and 0·83 returned. This system thus comes out considerably better even than the special shunt. But it must be remembered that that shunt system is new, and, as far as we know, nothing like it has been in use.

Ordinary Series System on Constant Pressure.

Case VII.—Present practice would demand series motors on the constant-pressure system with no return. The corresponding figures would then be 1·5 taken in, 1·5 wasted, 0 returned. The constant-pressure intake is 15 per cent. more, and its waste more than three times.

DISTRIBUTION AND PLANT FOR RAPID URBAN SYSTEMS.

The constant-pressure system has 2,000 volts, and currents varying up to, say, 600 amperes per train. If the

trains work at 2 minutes headway, allowing as margin 90 seconds per station, a train takes 24 minutes from end to end, and we may consider that 12 trains are on each line at a time, making 24 running.

The constant-pressure system has up to 2,000 volts per train, and a current of approximately 600 amperes. It is hardly necessary at the present stage to discuss the cost of distribution or of the plant installation. As to distribution, it is a simple matter if we use 2,000 volts on a line 12 km. long. Such a railway would naturally be worked on the three-wire system, so we would really have 4,000 volts. There would be no sub-stations, three-phase converters or transformers. The system of distribution for the series constant-current system requires a little more consideration. If we use a maximum of 2,000 on any train we may have a very much higher pressure in the line; for instance, we may work up to several thousand, say 10,000 volts. If the 2,000 volts is the highest we can make motors to suit, and if there is no other limit, we can obviously go up to anything within reason. As the average back pressure is 164 volts per train with 600 amperes, 4,000 volts would run the whole railway in series, provided the trains were carefully regulated as to time. With an earthed middle, this means 2,000 volts each way. But such regulation is quite out of the question. We would probably need to have 8,000 volts available, or even more. Each line may be worked with a maximum of 4,000 volts.

As to the station plant, the series is clearly smaller; but it is also of an unusual character. The dynamos are series-wound, driven by engines at constant torque with variable speed. Such engines are more economical and last longer. But there is a further difference. The constant-current system has little more than half the average output; and has therefore approximately half the coal consumption, but the size would be about two-thirds, for though the series trains take little more than half the energy, they take the same maximum loads, though they keep them on for a shorter time. Compared with the constant-pressure system with series motors, and no return by braking, the series system needs only about half of the plant at the generating station. An overload cannot occur on the series system. If all the trains started at once they would merely run slow till the matter righted itself.

Constant Pressure Slow Urban Train.

Case VIII.—We will now come to something more like present practice, and we will assume an acceleration of 0·4 m. (1·3 ft.) sec². and 500 volts. As the acceleration is smaller, we will assume that the braking is not done electrically; and that the motors are series-wound, giving normal back pressure at $\frac{2}{3}$ of full speed. It is difficult to take a case from actual practice, because actual practice depends so much on the idiosyncrasies of the "train-boys." The train-boy may do almost anything in the way of wasting energy. In addition, the resistances go in steps, and it is not possible to work with constant current on a constant-pressure system. For the purposes of comparison only, we will go on with the same sort of assumptions in all cases.

If the maximum speed is taken as 43·2 km. (27 miles) per hour, the motors may be designed for full current at 8 m/sec. We need not give the calculations; the result comes out that the train absorbs 11,000 kj. (3·06 units) between stations.

Case IX.—The series-constant current system absorbs 8,500 and returns 6,050, thus wasting 2,450. The kinetic energy in both cases is 7,200. So the low-speed constant-pressure, Case VIII., takes roughly 1·5, wastes 1·5, and returns 0. Constant-current series, Case IX., takes 1·2, wastes 0·35, and returns 0·85. The time may be taken at 95 seconds. The average power taken by the parallel system is 116 kw.; by the series constant-current, 26. The maximum power of both systems is 404 kw.

The trains being slower, we may allow 3 minutes head-way making 16 trains running. If the system is divided into 4 sub-stations, the parallel will have an average output of 464 kw., and a maximum possible output of 1,616 kw. The series has an average of 104 and a maximum of 1,616, which is troublesome, but there is much less chance of the series coming up to 1,616. It would probably be safe to allow for 1,200 kw. for the parallel, and 900 kw. for the series. The parallel system must therefore handle a current of 1,200 amperes, and the series 900. It is assumed that the three-wire system is allowed with 500 volts each way, as the 1,000 volts is then between different tunnels. The series constant-

current system is at a considerable disadvantage compared with the parallel in the cost of distribution. For a given maximum such as 500 volts each way, the conductors are twice as heavy. The maximum loss is always going on in one half while the other is idle, so a lower current density should be allowed. Working with 900 amperes and allowing, say 150 amperes per square centimetre, we would need 12 square cm. extra along the railway, for series, say 2 square inches. This amounts to nothing appreciable in the cost of the railway, and is quite insignificant in comparison with the saving of plant.

In the sub-stations, the parallel system has transformers with no moving parts, and converters in motion. The series system has moving converters only. As they are for smaller output than the rotary converters, they would cost about the same.

We may now summarise the results so far obtained for urban railways, first completing the table for comparison :—

TABLE V.

ENERGY REQUIRED BY VARIOUS SYSTEMS (KINETIC ENERGY OF TRAIN = 1).

Case.		Maximum Power.	Mean Power.	Energy Taken.	Waste.	Returned
I.	Series with electric braking	1,550	210	1·5	1	0·5
II.	Series without electric braking	1,035	250	1·2	1·2	0
III.	Shunt with electric braking	1,035	84	1·2	0·4	0·8
IV.	Series Constant Current with electric braking.	1,035	0	1·	0·	1
V.	Constant Pressure Rapid Urban Service ...	1,178	175	1·5	0·83	0·6
VI.	Constant Current Rapid Urban Service ...	1,178	104	1·3	0·49	0·83
VII.	Present Motor Rapid Urban Service ...	1,178	312	1·5	1·5	0
VIII.	Series Motors on Constant Pressure Slow Urban Service ...	404	116	1·5	1·5	0
IX.	Constant Current Slow Urban Service ...	404	26	1·2	0·35	0·85

Cases I., II., III., and IV. are hypothetical cases for rapid urban work.

Cases V. and VI. are practical cases of rapid urban work: but the constant-pressure system, Case V., is altered by the adoption of a special shunt motor system which is not in use. In spite of that the series system, Case VI., has little more than half the average power, to give the same speed.

Case VII. is rapid urban with series motors on constant pressure and no return of energy on braking.

Cases VIII. and IX. are parallel and series for slow urban railways as at present used. The series system takes less than a quarter of the power.

Against the series system generally, it may be urged that it is untried, and demands special switch-gear, and a distributing system which has not yet been worked out.

Main Lines.

General Considerations.—The problem of the main line is radically different. In the first place, we have to deal with goods and mineral traffic as well as passengers, and we thus have to handle loads of widely different speeds. We also have to allow for facilities for shunting. Sidings introduce great complications in the way of electric conductors, and it is probable that it would pay better to work these by steam or accumulator locomotives instead of including them in a main line net-work. In addition to gravity shunting, there are other methods worth considering, but they would make this paper too long if discussed now.

The capital expenditure on railways in Great Britain and Ireland per mile of route (*i.e.*, disregarding the number of tracks) is at the rate of £45,300, or less than one-tenth of the expenditure on the Central London Railway. This at once shows that any outlay on a generating station for a main line is a much larger proportion of the total capital than it is in the case of tube railways, and is therefore of greater relative importance.

In considering the traffic which passes over a main line, we see at once that it is very much smaller per mile of route than on urban lines. In other words, main lines are not worked to their full capacity to the same degree as an urban line, and cannot create traffic to the same extent.

The working costs of steam railways for 1900 as given in Table VI. are of interest, and may be compared with those of the Central London Railway given in Table I.

TABLE VI.

COST PER TRAIN-MILE ON STEAM RAILWAYS DURING 1900.

	Pence per train-mile.
Maintenance of way	5·69
Locomotive power	11·53
Rolling stock	3·09
Traffic expenses	11·54
General charges	1·47
Rates and taxes	2·24
Government duty	0·21
Compensations:	
Personal injuries	0·20
Damage to goods	0·31
Legal and Parliamentary expenses	0·18
Miscellaneous	0.39
Total	36·84

At first sight it will be said that the comparison is not favourable to electric traction. But there are two items which might possibly be reduced. Thus the maintenance of way would probably be less than with steam, on account of reciprocating motion being avoided and, probably, the use of lighter locomotives or the multiple unit system. The locomotive expenses for steam traction are already less than the figure for the Central London Railway, but it must be remembered that the latter includes energy required for lifts. Consequently it is very possible that this item might be lowered by electric traction. It is impossible to compare the costs of traffic expenses, because the conditions are very different. Possibly this item might be reduced to some slight extent.

Summing up, we may say that, although an increase of traffic would result on the suburban parts of a main line in the adoption of electric traction, it does not follow that there would be a large increase on main lines proper. The success of electric traction on main lines must therefore depend largely on a reduction of running cost. In other words, the question of all-over efficiency of distribution is much more important on main than on urban lines. It is

wholly a financial question, and it follows that, neglecting any increase in traffic, the reduction in running costs must be enough to pay for the extra capital. It is too often assumed that electric traction on main lines is necessarily advantageous, but such is not the case. Of course, it is imperative, in the first instance, that the traffic density should be above a certain figure, otherwise the running costs will be increased rather than diminished.

It must be remembered, however, that we have about reached the limit of speed of steam-drawn trains. Our gauge is unfortunately less than modern railway engineering demands, and it is impossible to alter it now. The tunnels and bridges also cramp us. Electric equipment, however, gives us as much power as we can want on a train of present height and gauge, and in addition gives it with steady running. The first demand on long lines to be met electrically, will probably be rapid expresses, and it is with that in view that we have taken 1,000 kilowatts as supplied to each train.

Saving of energy during acceleration, and its return while braking, are no longer of paramount importance. The parallel system, therefore, seems to have the advantage in every way. There are, however, two factors which come in its way. In long-distance railway work, the maximum power is needed at the highest speeds. Either system can be designed to supply that; but the parallel has less flexibility as to speed. If the motors of an express engine or train are designed to take their full current and give their maximum power at, say, 100 km. (62·5 miles) per hour, to work them at 80 km., 20 per cent. of the power must be wasted in resistances. The three-phase system is most unfortunate in this respect, for its proper speed is perfectly definite. The constant-pressure direct-current motors, if series-wound, can be wound for a little less than full speed, as already described in connection with urban railways; and if the train is over-motored, the top speed can be obtained economically. Nothing like this can be done with the three-phase system. A train once late can only make up time by shortening its stay at stations. The series constant-current system gives a perfect solution of the problem. The motors give the maximum torque normally even at the highest speed. If a lower speed is needed, one motor

is used, giving half the torque; or two motors in parallel, giving a quarter of the torque. By alternating from one arrangement to the other, any speed can be obtained economically. Shunting the fields gives a further adjustment.

There is another question to be considered, and that refers to the limits of pressure. Shunt motors cannot well be made for high pressures. Even 2,000 volts is very high for shunt machines. For 2,000 volts probably four machines in series would be used. Their armatures could be coupled in parallel or series. Whether series or shunt, there is next the difficulty as to the pressure possible on the commutator. If there are two motors and they have to be in parallel, from 1,000 to 2,000 volts would be practical; but it would hardly be advisable to go higher, at present at any rate. We can hardly, therefore, utilise a higher pressure than 2,000 volts on the constant-pressure system. On the constant-current series system, as long as we do not have more than 2,000 volts per machine, or 4,000 per train if we have two motors, there is no limit to the pressure that can be used. It must be remembered that if there are two motors in each case the series constant-current system can always have twice the pressure of the constant pressure, as in this system the motors are in parallel on the full pressure, while in the constant-current series system the motors are only in parallel on low pressures. To deal with high pressures such as 10,000 volts, the motors must have suitable insulation, or the whole motor must be insulated, working through a Raffard or some such coupling. Such a coupling has already been proposed, and with certain modifications used, to convey the power from a spring-borne motor to the axle.

We may take a passenger train as needing 1,000 kw. at its maximum speed. This is more than is used at present; but there can be little doubt that higher speeds will be adopted as soon as they can be obtained. Compared with the powers we have been considering in connection with urban railways, no one can object to 2,000 kw. on a main line express at the high speeds of the future. The power here is used to overcome traction resistance, not to get up speed, or kinetic energy only to be dissipated again almost immediately. We may for the present discuss 1,000 kw.,

which is roughly half as much again as the power of an express engine.

Constant Pressure Main Line.

We may thus take it that we have to supply 2,000 volts and 500 amperes per train. As all the four rails can be used as intermediate conductor, and the three-wire system is available, the conductors have to carry 500 amperes per train. There is no reason why goods and mineral trains should not have the same power. It makes no difference to the distribution if the goods trains take less power and are more frequent. As they go slower they can have a smaller distance headway if there are no passenger trains. Though the traffic near the terminus may be considerably greater, we will take only from two to three trains an hour as a fair average. They will naturally be thickest when slow. If they are going at only 64 kilometres (40 miles) per hour, we have 3,000 kw. to be supplied every 64 km. for each line. At this rate we have sub-stations every 128 km., we have to transmit our power up to 64 km. on each side of each sub-station. This, at 150 amperes per sq. cm., means 10 sq. cm. of copper for each line, tapering down, or an average of 5, or less than a square inch. This costs for copper only £270 per kilometre (£430 per mile) per track. The loss of pressure is also not at all serious from the cost point of view, but it is from the regulation, and consequent variation of pressure on the train terminals. If we double the area of the conductors we have a maximum drop of 400 volts, and a mean drop of perhaps 100 in ordinary traffic. It would thus be easy to arrange for sub-stations every 64 kilometres or so; but we have assumed the three-wire system with 2,000 volts a side. It may be more prudent to limit the distance to something like 40 or 50 kilometres. Unless the distances can be great enough to enable distribution to be carried out from the generating stations themselves, there is not very much point in having the sub-stations very far apart. It would be a very great saving if we could avoid sub-stations and all their attendant costs and losses, but 2,000 volts will not permit that. The generating stations should be at places where they can sell energy for industrial purposes, so as to get good load-factors

and large outputs. At present this means near large manufacturing towns. Some day people may realise that the way to deal with the congestion of large cities is not to provide more and more facilities for people to get into them, but to move the factories out of them.[1] A power-station on a main line in the country where the railway crosses a river would be a good nucleus for a new industrial city on sound principles. On the other hand, as Mr. Highfield has pointed out, producer gas-engines may be used to work rather numerous generating stations; the gas being supplied by pipes.

Series Main Line.

The series system has the advantage of doing away with the sub-stations.

The constant-pressure example had a current varying from 1,500 down to 0 along the line. For series work it would be quite reasonable to take a current of, say, 500 amperes. This needs 2,000 volts per train; so for 8,000 volts, with earthed middle, that is 4,000 each way, we can run 4 trains on each line on each side of the station. If the trains have a speed of 64 k/h. as before, and a headway of 20 minutes, we have a distance of 85 km. on each side of the station, or no less than 170 kilometres (or 106 miles) between stations. Such a distance as this between generating stations would be considered moderate even in America. The leads would have to be somewhat large, however. To keep the maximum loss in leads down to 1,000 volts we would need a current density of about 75 amp./cm², and for 500 amperes this means 6·6 sq. cm., or roughly a square inch of copper each way. Taking the density of copper as 9, we need $6{\cdot}6 \times 9/10 = 6$ tonnes of copper per kilometre and another 6 for return, or £720 a kilometre, or £1,150 a mile for copper for each track. The series-system thus gets over the difficulties of the sub-stations altogether. It has, of course, many disadvantages. The collection is more difficult, as the current is greater, and there must be double collectors. The problem of collecting is not dealt with in this paper; but that is by no means because it is not real; it is rather because there is no solution to offer. It may prove very difficult to collect 500 amperes at 120 kilometres or 75 miles an hour.

[1] Madgen, *J. Soc. Arts*, February, 1902.

It is difficult to foresee the development of gas-engines, and it is therefore impossible to say whether large engines will be best at constant speed and varying load, or constant torque and varying speed. Constant speed may be good in certain cases, but a fast train cannot run at maximum speed over all parts of the line alike, and the variation that is necessary for fast is not needed for slow trains.

Other Systems.

The series and parallel direct-current systems have been discussed at such length there is little space to devote to others. This is not because the others are unimportant, and it may be as well to refer to various ways of dealing with the problem. Some of the proposals or systems are well known, and need no description, only discussion; while others are, we believe, new, and will need a little fuller description.

Three-phase Constant Pressure.

This system is in use in several places on the Continent. For short urban railways the three-phase has no advantage as to pressure, for the direct current can use up to 4,000 volts on the three-wire system, and that is enough for such short lines.

As to efficiency, it is nearly on a par with the shunt system, in which the normal output of the motors is at full speed instead of about two-thirds of it. It is thus behind the direct current as commonly used, and far behind such a direct-current system as Case IV. The energy is also returned with a low power-factor, which is a very serious drawback.

For urban railways with low pressure it has the advantage of absence of moving machinery at the sub-stations.

For long railways it has many advantages. High pressure can be used, so that moving machinery at sub-stations is avoided, and the sub-stations may therefore be mere transformer boxes. Some of the systems to be described later have all these advantages. The disadvantages are three collectors, constant inflexible speed, and complication.

Three-phase Constant Current.

This is a rather peculiar arrangement. It is shown diagrammatically in Fig. 9. Each train is worked from one three-phase generator. This is driven by a constant direct-current motor, or by a special engine, and transformation may take place between the dynamos and the train motors.

Fig. 10 is another modification of the system. The sections are as long as the shortest space headways of the trains. An engine at the generating station, or a dynamotor at the sub-station practically takes charge of a train and feeds it from section to section. Any section not in use is not electrically alive. Such a system as this can only be for long lines, and it is doubtful whether its disadvantages, namely, complications and three collectors, do not outweigh its variable speed, its efficiency, and its lower pressures on exposed parts.

According to Fig. 10 the distance transmission is effected by constant direct-current, and local distribution at high pressure by three-phase circuits.

Transformed Direct. Constant Current.

This is a modification of the series direct system already described. Its object is to get over very long distances without excessive pressure on exposed parts. The diagram Fig. 11 explains itself.

Constant Pressure Simple Alternating.

The easiest sort of distribution of all is the simple alternating, as it needs only still transformers to enable the engineer to get over very long distances. The difficulty is to use the alternating current when we have got it to the train. For long lines the difficulty is not serious because the kinetic energy of the train is not important, so that waste during acceleration need not be considered. All that is wanted is a mechanical friction coupling. If energy equal to the kinetic energy has to be wasted on starting, it may as well be wasted in mechanical friction as electrically. The motor, therefore, always runs at full speed, and the train is clutched into gear by a friction clutch, capable of

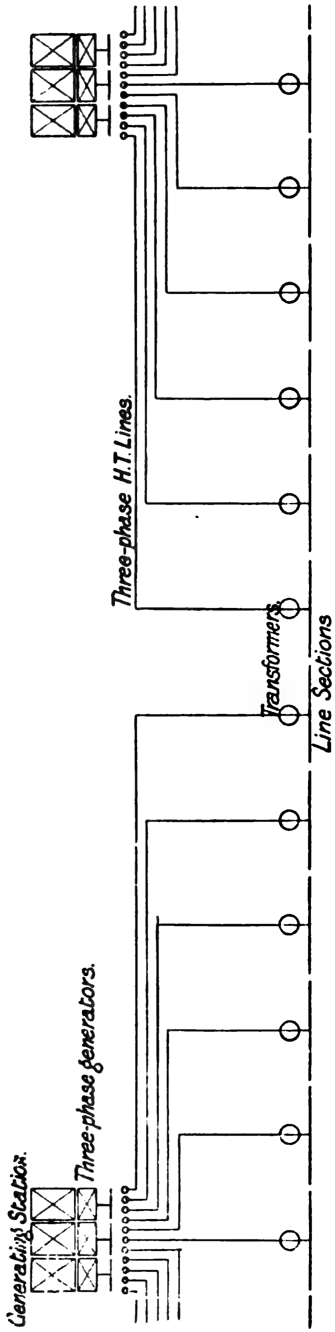


FIG. 9.—Three Phase Constant Current, No. 1.

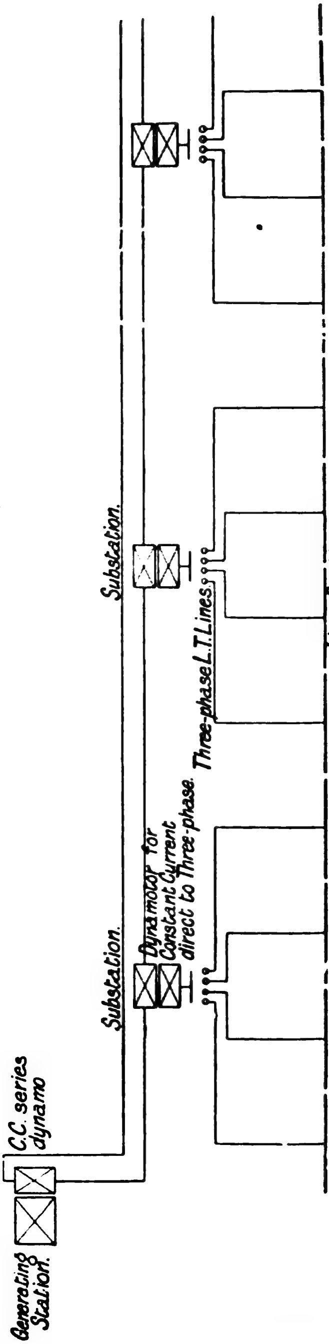


FIG. 10.—Three-phase Constant Current, No. 2.

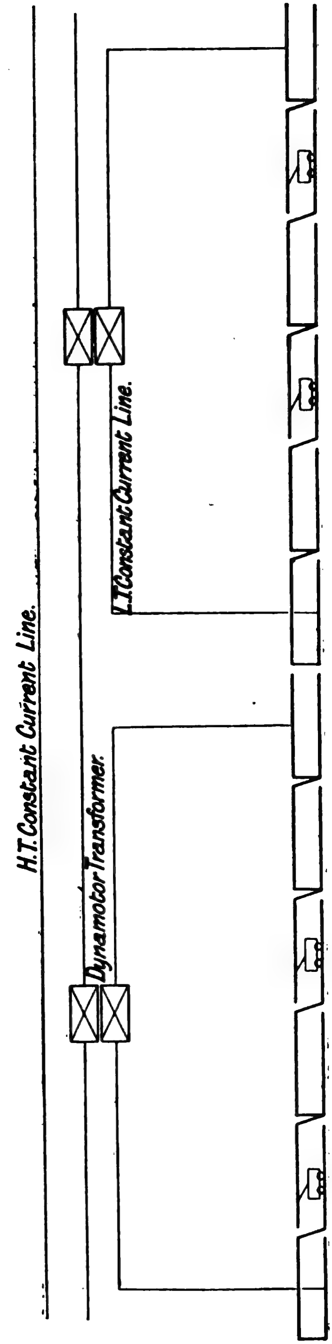


FIG. 11.—Transformed Direct Constant Current.

getting rid of some 50,000 kj. in a few minutes. A simple method is to let the field rotate when the train is stopped. To start, a brake is applied to the field, which slows it down and finally clutches it. On releasing the fields the pull is taken off the train and it slows down. This system returns no energy. It has the disadvantages of constant speed; but has very many good points for long-distance work.

Constant Pressure Alternating and Leonard.

In this system the alternating motor drives a direct-current dynamo on the train. This goes at constant speed, but gives any pressure wanted by field regulation. The dynamotor may run at turbine speeds, and may therefore be small. This gives everything that can be wanted, but at the expense of low efficiency and extra weight and cost. For urban lines, where the distribution is not difficult, the system is inferior to those already described, and is expensive. For long lines efficiency at starting is unimportant, and the inefficiency and weight and cost are very serious.

Conclusion.

The object of this paper is not to demonstrate that the series system is the solution of all our difficulties, nor that this system is good and that system is bad. Our aim has been rather to treat the electric railway as if it were a completely new problem in which nothing had been done, and to review as many different ways of meeting the difficulties as could be thought of for the purposes of the paper. Many of the methods mentioned will seem out of the way and curious, but whether they are or are not worthy of adoption or even serious consideration, they may be worthy of discussion, especially if capable of modification and improvement.

The paper may be broadly summed up as indicating reasons for holding that the treatment of railways as if they were tramways is bad, and that even in short low-speed urban railways a particular shunt system would be considerably better than present practice. Series constant current, it is urged, is better still.

For long railways it is important to have the same system as short urban or suburban lines, as the systems will be connected. Long lines are thus influenced by suburban and short full-sized urban lines, but not necessarily by tubes, as they will most likely be independent. It is quite satisfactory, therefore, to have one system for small-bore railways and another for full-sized. Whether the series is the best solution for urban and main-line railways, if they must have the same system, is another matter. Perhaps, on the whole, the single alternate-current gives the simplest solution, when used without any dynamotors on the train. Or, where acceleration is of great importance, such dynamotors might be used.

The main problem of electric railways is to get varying speed from constant pressure. The electric method of doing this with two extra machines is clumsy and inefficient. A mechanical variable speed gear would be of incalculable advantage, but it is not easy to design one fit for locomotive work.

The special shunt direct-current arrangement with weak fields solves the difficulty to some extent, but it involves rotary transformers or dynamotors at the sub-stations.

In considering the expense of stations and sub-stations it should be borne in mind that they will also be signalling centres. If the trains are worked electrically, the power can be cut off without communicating with the driver, and the driver will have no need of signals. In some of the systems sketched in this paper it is easy to signal the exact position of all the trains to the sub-station or station. Models will then move along plans of the railway, so that the trains are controlled entirely from on shore, so to speak. All the driver has to do is to keep a look out for anything on the line. He also has to start and stop at stations. As the ordinary signalling will be replaced, there will no doubt be a telephone wire along the railway with call-boxes at intervals. In case, say, of an accident, such, for instance, as a landslip, the difficulty of stopping a train that is due will not exist. Any one can communicate with the station, and the train will be stopped. The present chaotic demoralisation of suburban railways by fogs will not exist at all. It will be as easy to run in fogs as in the dark.

But we shall not reach all these perfections very soon unless we look where we are going.

The PRESIDENT: Gentlemen, it is not my intention to detain you by any remarks at the present moment, except to say that we are all greatly indebted to Mr. Swinburne and Mr. Cooper for this very delightful paper. The President

Mr. ALEX. DOW: The paper as printed, and as repeated at large by Mr. Swinburne, is a temptation to a full discussion rather than to a condensation. I think, however, that my remarks will be of value only in so far as they represent those things that (so to speak) every fellow does not know. I will not attempt to touch on the matters that every fellow does know. The paper is to me a cause of considerable fond recollection, as it were. I had a little intercourse with a series system some thirteen years ago, and the switches and so forth indicated struck me as not entirely novel, but as of things which, with other dreams of an early electrical experience, were things to be talked of and told of, and not to be put into practice. The line I recall was very light; a street railway of about four miles long—it was a tramway rather than a railway. The possibilities of electric braking by backing up the motor brushes were perfectly realised. It was a delight to take one of those cars over the top of the hill and coast down on the other side, controlling it absolutely by pulling up or down on the brushes, and increasing or decreasing the counter E.M.F. The return of energy to the station was also absolutely perfect—too entirely perfect, in fact; because inasmuch as the series generator declined at times to receive assistance kindly, and rather resented the sudden change from a matter of forty Mr. Dow.

Mr. Dow. or fifty H.P. *plus* to forty or fifty H.P. *minus* in its own load-curve, it was necessary to keep a man at the brushes all the time. Incidentally, the man wore blue glasses! Nevertheless the theoretical advantages were all there. Even the switches were not so bad as they might be. They were worked by a pin on an overhead trolley. I am speaking, of course, of a United States experience. The pin worked those switches very nicely. I cannot recollect just how we avoided reversing the current through the motors each time we ran off a section, but we did it in some way. The current continued practically through the motor without interruption, and everything usually worked all right. When the switch did not work all right, the conductor made a few remarks appropriate to the occasion, the car stopped, and the conductor aforesaid went back with a pretty long pole and hit the switch! If the motor man had put his brushes in the proper position, the car stayed stopped until the conductor got on. Once in a while the motor man forgot and the conductor had a chase. My last memory of that system is that I took the floor in a meeting of a much smaller assembly and one of much less standing than this, to talk for that system as in duty bound, being in somewhat of the situation of the expert witness; and I had just got nicely in touch with the subject when my coat-tails were pulled—"Sit down, old man, we are taking it out."

Speaking now somewhat from theory, I think that some of Mr. Swinburne's minor premises are not warranted. I do not think he is warranted in saying that a series-motor requires no starting resistance. It may be started, as he says, by simply opening the short-circuit switch. If he had ever opened out the short-circuit switch of a 125 H.P. series-motor taking 40 amperes constant current, he also would have concluded (as I did) that it was not entirely a ceremony to be undertaken without due preparation. The method in which the motor got a move on itself and jerked things around was rough, at least. It was quite true there was nothing connected to the motor but a pump, and the pump did not say anything; but if we had had a train connected and a few car-loads of passengers behind us, there would have been protests, and letters would have been written to the American equivalent of the *Times*. Mr. Swinburne's theoretical motor not only has no resistance, but has no inductance, otherwise he would not contemplate the passage instantaneously and smoothly of a current of 500 amperes (more or less) through the said motor. Resistance, shunting of some kind, is necessary. The neatest arrangement, perhaps, is an equivalent of the well-known Ayrton shunt for a galvanometer, which works very beautifully. Something of that kind must be used on series-motors in large sizes; in small sizes it is not at all necessary. In fact, the series-parallel working of large constant-current motors suggested by the authors of the paper means just as much controller complication, and just as much controller trouble, and, incidentally, just as many controller repairs, as does the present method of constant potential motors. The return of energy to the line with Mr. Swinburne's assumed varying speed of engines theoretically would not have the commutator difficulty against it, but I am inclined to think that if a reasonable amount of fly-wheel were used in these engines, and the engines had the usual

reluctance of large engines to get a move on them—they are assumed to be of 1,000 H.P. or so—there would be more or less, *more* rather than less, spluttering of the commutator at the moment that a train went over a bank and started downhill with its motors backed up. I am inclined to think that the spluttering might be described to an American audience as a 4th of July celebration: we send off fireworks on the 4th July in America. Mr. Dow.

Mr. Swinburne says on p. 999 that the current need not be large; but on p. 1002 he mentions 900 amperes as a possible current. That strikes me as large. The section switches are stated to be sparkless. So they are in theory. In practice they either open the circuit, in which case they certainly do spark somewhat—there being 22,000 volts at the back of the 900 amperes it is only natural that they should spark—or else they short-circuit the section, in which case your motors buck—and they buck viciously. It is equal to the full negative acceleration suddenly applied, and the result is that your passengers are all piled up in the front end of the car! The distribution also is really a trouble. It is not so simple as it looks. You cannot use the sectional system and get good economy, because you will find you are obliged to put a separate dynamo on each section. It works out that way practically. We theorised that we could put the machines in multiple and put them in series, and we did so, but it came to the one dynamo per section in the end. Dynamos were not so good then as they are now, and might behave better nowadays, but the line troubles would be just the same. The feeder and main system is obviously not applicable. I want to point out incidentally that the whole question of details of control is omitted—I won't say evaded—and to say again that it is decidedly complicated.

I want to point out also that the resistance losses of the present methods are not always losses. They are really large; but in the United States, where we heat our cars for seven months in the year, we are beginning to avail ourselves of those resistance losses and also of the energy losses of the present methods of electrical braking to heat our cars. Heating may not be so necessary here, but there is quite a valuable return.

So much for detail, and now a few remarks on general principles. The storage battery has been eliminated altogether from Messrs. Swinburne and Cooper's premises. I think it is a very serious mistake to omit storage batteries from consideration. Those who have seen, or have even recognised in the published descriptions, the ridiculously small amount of storage battery that gives the South Side Elevated Railroad in Chicago (one of the busiest urban lines in the world) a smooth-running and easy-running power-house, and that likewise maintains the voltage fairly uniform along the line, must see that even with batteries so unsatisfactory from a mechanical point of view as the lead batteries still are, the storage battery is an essential of tube and suburban service. Messrs. Swinburne and Cooper also omit consideration of the more recent practice of running motors in sets of four instead of sets of two. That modifies the losses in acceleration; the first step of course being four motors in series. The conditions of the

Mr. Dow. multiple unit system are theoretically common to both the series method and the constant potential method. Unfortunately, however, it is only with the constant potential method that the difficulties of collection of current from trolley wire or rail are eliminated. If you must handle the full current in every unit, you lose at once one of the principal advantages of the existing multiple unit system, in which each unit only takes that current from the constant pressure supply which is required for its own propulsion. The amount of current to be taken by one collector is thus reduced. With regard to the question of a limiting voltage for constant current working, 22,000 volts certainly seem a fairly high limit. My observation in all lines of electrical development is that when we set a theoretical limit that neither we nor our children are going to reach, we run up against that limit about the year after next. On the other hand, when you work at constant pressure there is *no* limit; neither to the size of the units nor to the number of machines you can put in multiple. You can keep on indefinitely. Units of 8,000 H.P. are being built regularly, and I need not tell you here how large units can be built because you showed us how to do it.

In the matter of acceleration, this is really a practical note—not theoretical. The limit of acceleration is what people will stand without kicking—and they will stand a deal more than you think, if you only get them into it slowly. I am told semi-officially that the Central London Railway, the Twopenny Tube, represents the best practice in handling passengers and the quickest acceleration in London. I find it excellent practice—exceedingly creditable; but I do not find that it has as big a move on it as I know is possible and think can be obtained. It represents a big improvement over some other railways in the neighbourhood, but still it is not anywhere near the limit: in fact my observation of it was that the acceleration was gradual and pleasant and that the train men were quite, let me say, ladylike. We on the other side are accustomed to being somewhat hurried; and we are not unused to be shifted forward by a quick application of the brake when we block up the rear door, or jerked backward by sudden acceleration. We find by observation—I have observed it in the town in which I live, where we have changed from horse cars to a rather inferior electric service and then to a very superior electric service within the last eight years—I have observed that the handling of the passengers and the acceleration are both very much quicker in our later practice than they were before, and far beyond what I find in London now. Toleration is a matter of individuality. I confess that I do not mind at all being jerked about quite a bit on an American electric car, and that I am unfortunately rather worried (not to say internally troubled) by the rocking, sideways, jolt on the top of a London 'bus. If your people will stand the one, they will surely become educated to the other.

I must ask you not to give the weight to my final remarks that you would give to remarks emanating from a recognised authority on electric railways; lighting being my own special work. My expectation as to the long-distance service of the future is that the motors will be composite wound, shunt and series, the series field being com-

mutated in acceleration: and the motors returning energy to the system as shunt-wound machines during the first period of negative acceleration. The shunt field will be weakened in the last stage of acceleration and strengthened for braking. Such motors are not yet in service on cars. I have, however, in constant service two motors of 150 kilowatts which act reversibly as generators; they are, in fact, the direct-current ends of small motor generator sets. You must not overlook for a moment that when you want to return energy to the system by braking you will have to do so at a higher voltage than the nominal working voltage, and that the effect of line-drop is to increase the difference between running voltage and braking voltage. A common stationary shunt-wound generator, when used as a motor, is allowed to run at a lower speed. Here, again, the conditions are such as to make difficult the return of energy to a railway system by braking; because the braking—that is the *generator*—speed is lower than the motor speed. My two motors come in an intermediate class; their speed is virtually constant, being fixed by the frequency of the alternating-current system. They run as motors with the shunt field weakened to the point of instability, so that a few cumulative series turns have to be used to keep them steady. As generators at the same speed, the series turns are short-circuited and the shunt field is given full value. They get current as motors at 256 volts, and generate full output at 290: not a long range, but still enough to illustrate what I expect to see done in railway work.[1] Mr. Dow.

As to the development of long lines, I look for the growth round each large city of a suburban service, which I think will probably be a development of the tramway service—I think so. I see no reason to the contrary. I look for the development of through electric service to come just as the original developments of through service came, by the uniting of the outward growths from local centres so that the network becomes continuous.

These two opinions—as to future motors and future through lines—are offered as my individual opinions.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected, viz.:— The President.

Members.

Chas. Hesterman Merz.	Henry Rowley.
Leopold Paul Stark.	

Associate Members.

A. E. Barber.	Theodore C. Parsons.
Charles Edward Douglas.	James Archibald Robertson.
Thor Peder K. Hammarskjold.	Richard Jones Rosser.
Harry Jackson.	Charles Frederick Trippe.
George Lauchlan.	Wm. Jas. Roberts Wray.

[1] The motors may have a separately excited field instead of the shunt field. There are advantages therein, both constructional and operating. To secure these advantages we obviously need a reliable portable storage-battery; something much more mechanical than the present lead batteries, but not by any means unattainable, even to-day.

Associates.

Samuel Edward Barnes.
Abraham Bernstein.
Chidley Dormer Coote Cummins.
William Drysdale.
Hubert R. Edmonds.
John Henry Edwards.
Hugh John Holder.
Harold Henry Lindon.
Thomas McIlwraith Mackay.
Arthur Marston.
Ernest Montgomerie Martin.
James Hayne Stephens.
Henry I. Van Straubenzee.
Charles Robert Walker.
John Harold Woolliscroft.

Students.

Mohomed Alisan.
Richard Amberton.
Douglas Howard Bishop.
Herbert Cecil Carter.
Lionel Stevenson Challis.
Percy James Clears.
Oswald Bertram Rowett Collins.
John Smyth Crone, Jun.
Arthur Edmond Davy.
John Robert Gillman.
Henry Montagu Lyons.
Archibald Norman McIntyre.
Robert Brett Perring.
George Rackstraw.

The Three Hundred and Seventy-Sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 10th, 1902—Mr. WILLIAM E. LANGDON, President, in the Chair.

The minutes of the Ordinary General Meeting held on March 20th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Bradford Leslie.	John William Towle.
Charles Davis Taite.	Arthur Wright.

From the class of Associates to that of Associate Members—

Benjamin S. Hornby.
Leonard Wilson.

From the class of Students to that of Associates—

Leslie Henry Andrews.	Harry Augustus Nott.
John Eustace.	Norman C. Sawers.
Bernard de M. Mertens.	Edmund Ramsay Spence.
Leslie Robert Morshead.	Francis Samuel Stacey.

Messrs. W. P. Digby and R. Grigg were appointed scrutineers of the ballot for the election of new members.

Donations were announced as having been received since the last meeting, to the *Library* from Signor Ulrico Hoepli and Mr. P. V. Luke; to the *Building Fund* from Messrs. H. G. Beeton, R. C. Quin, and L. Wood; and to the *Benevolent Fund* from Messrs. W. E. Langdon and J. H. Woolliscroft, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have to announce that at the next meeting the Council's list of nominees for the Council for the session 1902–3 will be read. The President

We have now, gentlemen, to resume the discussion on Messrs. Swinburne and Cooper's paper. This paper has presented to us problems associated with railway work. The whole subject is one of intense interest, and the authors have evidently viewed it from

The President.

various points. The problems that they present are such as will, I am sure, commend themselves to the consideration of all members of the Institution. It is by considering problems conceived in this manner that we may expect to arrive at the best application of the means to the purpose suggested. I venture to hope that we shall obtain a good discussion, for the authors have bestowed upon it a great deal of pains, and it is one which is in every way worthy of the most complete ventilation.

Although in the opening of the paper the authors have stated their opinion that the main-line problem is not ready for consideration, yet at the conclusion they have bestowed on that branch of the question considerable attention. I am very glad indeed to see that they have done so, for I myself cannot see that great difference between the problem as it affects main lines, and that which affects what may perhaps be termed suburban lines. To my mind the chief underlying factor of the whole question is a constant load; and I look upon it that main lines or trunk lines ought to afford that constant load far better than any other class of railway. A suburban line has its heaviest traffic in the morning and evening; at mid-day it has light traffic in all probability, and at night time it has no traffic. The trunk lines coming into London have what may be assumed a constant traffic throughout the twenty-four hours. We see that these trunk lines coming into London are constantly extending and increasing their lines, which is a fair indication that they require them, and consequently that the existing lines, whatever they may be, are so full of traffic that they will not carry any more, hence the additions. At the same time I can recognise that there is a great difference between what may be regarded as purely passenger lines and those which deal with general traffic. There is no doubt a difference also in the mode of treating those lines that are devoted entirely to passenger traffic, and also a great difference in the treatment of what may be called omnibus traffic and long-distance traffic. Omnibus traffic, as has been shown by the authors in this paper, may be treated very advantageously in a different manner. In support of this the authors have brought forward, in Table IV. I think it is, results obtained on the Liverpool Overhead Railway, which show the great advantages to be obtained by acceleration. By the expenditure of 25 per cent., an advantage of something like 50 per cent. is obtained in the capacity of the line for traffic, provided the traffic is sufficiently heavy to make that demand.

It has been pointed out by the authors that one of the chief difficulties to be contended with is that of conveying and collecting the current. That undoubtedly is so, and I am afraid we shall obtain no solution of this problem until we see something in the direction of what has been done on the Metropolitan or on the Italian railways. We may look forward to either of these conversions to afford us the means of ascertaining the volume of current which might be collected at a given speed.

I would like to refer to one or two items that have been advanced by the authors with respect to the cost. It is stated that the capital cost per mile of line for steam-equipped railways averages £45,000.

The President.

In looking into the Board of Trade Returns I make the average cost something like £55,000. My object in referring to this point is that I do not think we should be justified in regarding the electrification of railways quite in this light, because in many parts of the country the cost of a mile of line of railway is very little, whereas in other parts it is exceedingly heavy; if we were to make a comparison with trunk lines I think the cost would be certainly three times as much. In regard to the working expense per train-mile, the authors give the locomotive expenses as 11·53 per train-mile. On reference to the Midland charges I find that the cost works out at 12·56 for the year taken by the authors. I give these figures because I am anxious that considerations in regard to electrical application should not suffer. Reference has also been made to the savings to be expected on the application of electricity to any of our existing lines. I think that these economies may be extended. Great economy would be effected by the abolishment of the number of pumping-houses and water-cranes; boiler repairs would be extinguished except for repairs at generating stations. The cost of repairs to the engines would be very much less, as would also coal stagings and sidings. In addition there would be a considerable saving in the load carried, because there would be no tender on the train; that would mean a saving of something like fifty tons per mile per train. All this is very much more evident on trunk lines than would be the case on suburban lines.

Of course the employment of electricity would admit of automatic signalling, and there would be a considerable saving in that direction; but signals could not be entirely abolished, because there must be points at which sidings and junctions would have to be worked and where signals would consequently have to be provided. I am fully in accord with the authors in respect to the desirability of employing a motive power for the trains capable of varying speed. I think that absolutely essential on any main line, or, in fact, on any line, of railway. The authors' problem of constant-current series-working is one which I think has such potentialities about it as deserve very careful consideration on the part of any one interested in the question. I heartily congratulate the authors on the excellent paper they have brought before us.

Mr Mordey.

Mr. W. M. MORDEY: I am sure we all feel a sense of responsibility in discussing this question of railway work. We appear to have reached the parting of the ways. Everybody seems to be feeling that the methods that hitherto have been sufficient for the moderate needs of short lines and of tramways are not sufficient for the requirements of longer suburban lines and of main lines. A good deal of attention has been drawn to possible alternatives to the methods used for all work in this country and for all work in America. The limits of direct-current working have been reached at such pressures as 500 volts, and it has been necessary to devise methods of feeding the lines by some higher pressure. Various methods have been proposed, as the authors in this paper, and Mr. Swinburne in a paper previously read before the Manchester Section have shown. I have myself, in conjunction with Mr. Jenkin, recently had the honour of a five-nights discussion on a

Mr. Mordey. paper that we read before the Institution of Civil Engineers, and I feel that I have very little new to say on the subject. But, if you will allow me, I would like to go over a little of the ground that I had to cover before the Institution of Civil Engineers. The author's courage is well known. I do not think he ever showed it better than by reading this paper. When, with Mr. Jenkin, I was trying to consider broadly the subject of alternative methods of electric railway working, we described all the known methods that occurred to us as at all practical, but neglected to say anything about the direct constant current series system. We were led, as a result of considering the question as fully as we could, to certain conclusions, one of which was that the method that possessed the fewest disadvantages and the greatest number of advantages was not a direct-current system at all, but was an alternate-current single-phase system. The author's paper may be taken as an antidote to the paper by Mr. Jenkin and myself. I think the antidote is worse than the poison. I will pass over the first part of the paper and the parts dealing with acceleration and so on, which I think are very good and useful. I may perhaps just say one word as to the emphasis that was laid on the question of accelerating very rapidly from the beginning. It was shown that there would be an advantage by saving that very small period of time. I think there is another way of saving time which perhaps is less costly, viz., the saving of stopping time. There is much to be done on town lines in the saving of time in stopping. Those who have been on the elevated railways in American towns will know with what precision and promptness that part of the service is always conducted. I have frequently timed trains on those railways and found the total time of stopping was only a few seconds—five, six, or seven seconds was quite common. That is helped very much by the arrangement of the carriages, which has been adopted on the Central London Railway. It is not so much the passengers who are at fault here, as the system of ingress and egress; the carriage doors are not suitable. By the system used in American towns, and on the Central London Railway, that difficulty is avoided. There is a space for stepping off and on, and there is some one to help the people, and to see that they are quick about it. The knowledge that they will be left behind and the doors shut against them, and that they cannot jump on the footboard as the train goes out has a very great accelerating effect on the traffic.

The question whether electricity is to be used for main-line railways is one that I do not think many in this room have any doubt about. I was surprised to find at the Institution of Civil Engineers that there was a great deal of doubt, that it was thought it might be all very well for short lines, and so on, but that the time was very far off—I think Mr. Swinburne was one of the gentlemen who took part in the discussion who said that—when we should have electricity applied to our main-line railways. I do not think I agree. Main-line railways, whether they like it or not, will have to use electricity. As you have just said, sir, the limits of the trunk lines are being reached. We must increase our speeds; we must increase the acceleration. Although it is possible physically to run at eighty miles an hour with an ordinary

steam locomotive—it is often done for short distances—eighty miles an hour is not a practical speed for reciprocating steam engines. The steadiness of running that can be secured by the even turning of the electrical motors, is a very great help—one that perhaps is not sufficiently realised—in enabling us with electrical methods to run faster than is possible with reciprocating engines. If I may use the expression, the waggling of the tail of the train, which is a result very often of the reciprocating of the engine, is a thing that we avoid almost entirely. The smooth running that is obtained, for instance, on the cars which run at forty to fifty miles an hour practically every journey on the tramways near Cleveland, Ohio, shows very clearly that it is possible to get much steadier running. This, I think, is mostly due to the absence of reciprocation. How are railway people to get over these difficulties—to attain higher speeds, greater acceleration, and steadier running—unless they adopt electricity? The reciprocation on the engines might be got over possibly by using steam turbines, but I have never heard even the warmest advocates of steam turbines propose to apply them to locomotives. If they did so they might get over the reciprocation, but they would probably not decrease the weight of plant that had to be carried. Whether electricity is coming for main lines or not, we know that it has come for short lines. We know that for extra high speed special lines—such lines as are contemplated between busy towns such as between Manchester and Liverpool, London and Brighton, and so on—it is hopeless to carry out the ideas as to high speed except by electricity. Those are the two extremes. And, surely on main trunk lines, especially if there is a distributed and steady load, as you, Mr. President, have just pointed out is necessary—we shall have the advantages of electric traction on those lines before we are very much older. If that steady and distributed load is necessary, it can be got by electricity even for the same amount of traffic, far better than by steam-drawn trains, because it will be easier to distribute the traffic in smaller units over a line of given length. That would tell very favourably on the size of the generating plant, on the sub-stations, and the transmission lines. Mr. Mordey.

May I pass to what I think is the most important part of this paper, the conclusions to which the authors are led that the advantages on the whole are in favour of some series constant direct-current system? I prefer to use the words "direct current" to "continuous current," because direct current is not necessarily always continuous. I was very much surprised at the recrudescence of this system. I thought I had seen the last of it. It has only been tried in this country once, and that was on the Northfleet line. I was present at the opening of that line in 1889. That was a very small affair—I think about three and a half miles long—with a very small amount of power. We heard from Mr. Dow that it had been tried in America, and that there, as here, as a result of practical experience, it proved a failure. The question came up at the Civil Engineers the other night. Mr. Swinburne mentioned this system, Mr. Siemens said it had not had justice done to it, and Lord Kelvin also said that it deserved consideration. I think it certainly does deserve consideration; every system deserves

Mr. Mordey. consideration. What we have to try and find is a system that has the fewest faults. We shall not find a perfect system, and we shall probably not find any system that has not serious drawbacks. There are a good many essentials for railway working. Mr. Jenkin and I have given elsewhere a list of what seem to be essentials, or at least points that are very desirable, and of those points I think there are ten or twelve that are almost essentials. I consider that the series constant direct-current system only has two of them; they are important ones, but I do not think they are important enough to turn the balance in favour of that system. The first is that no wasteful starting resistances are necessary, and that is a very great advantage, because it saves those enormous waves of current such as are shown on the Liverpool diagrams; and, secondly, it is possible with it to return energy to the line. The latter is, of course, of more importance on short lines with many stops than on long lines with few stops. But I cannot help thinking that the most essential point for railway working is that the overhead conductor shall be simple, and shall be, if possible, one conductor—that is to say, we must in railway working imitate, if we possibly can, the conditions that have been successful in tramway work as regards the conducting line. Whatever else may be complicated—in the locomotive, or in the generating station or elsewhere—I think we must have on the lines running through the country the greatest simplicity, and that can only be obtained by using one wire. With this series constant direct-current system you must have two wires; you must cut those wires at intervals to pass from one section to the other; you must have those wires of very high tensions; you cannot have one of them close to the earth, and practically at earth potential. The danger will be greater; the complication will be greater; the line losses will probably be greater, because the full current will be passing all the time, although not necessarily through the whole length of the conductor. There will be other difficulties. If two trains get on one section at the same time, it will cease to be a constant-current system so far as the trains are concerned. Another drawback to the system is that it cannot be extended easily. Any system to be successful must be capable, like the ordinary tramway system, of being extended indefinitely without complication, but with this series constant direct-current system you must have a limit to your volts, and you must have a limit to your current for each circuit. For instance, if you had a simple series constant direct-current system and not one of the ingenious modifications that are proposed by the authors, you would have to go back to the station and have a new system throughout whenever you got beyond the limits of pressure for a single circuit. Then there is another objection—you cannot transform except by rotating machinery. It is very important that the transformation should be done by stationary machinery. Another difficulty—and I think perhaps I have had as good an opportunity as anybody in this room of realising how great that difficulty is—is that of keeping a constant current at varying volts. Even when the current is only ten amperes and the maximum volts only two or three thousand, the difficulty is serious; but imagine a series circuit using three or four thousand kilowatts with

the pressure varying from a few hundred to three or four thousand volts and a constant current of several hundred amperes. Is there anybody in this room who can say that, with our present knowledge, it is possible to make a dynamo that would work smoothly and practically under such conditions? With an ordinary arc lighting machine, it is only the fact that it is a small current that enables you to collect at all. If you attempted to work with a large current you would find, I believe, that the problem under traction conditions would be quite insoluble with our present knowledge. Varying the speed to give constant current at various volts would not be practicable, because the speed could not be varied quickly enough to meet the great and rapid changes of demand on a traction circuit. I know that M. Thury, of Geneva, in his installations at Genoa and elsewhere, uses very high pressure constant direct currents. He has a number of machines insulated carefully from the earth and connected in series. But the motors are not of large power, the variations in volts are not violent and sudden, smallness and lightness are not matters of importance, and altogether the conditions are different and are very much less trying than those in electric railway work. M. Thury deserves our congratulations on the way in which he has solved with a considerable amount of success a very difficult problem. I do not, however, think there is any necessity for such a system. To me it seems merely another and a worse way of doing what can be done easily by alternate currents for all practical purposes. With the exception of M. Thury's work, which, as I say, is not at all on all-fours with electric railway work, there has been no attempt whatever to solve, so far as I know, such a problem as is involved in the system before us. The generators are a very great difficulty. You cannot work them in parallel—at least I can hardly imagine a direct-current varying-voltage machine working in parallel with any success. If you have constant-current machines, perhaps you would not want to work them in parallel, but even to work them in series would be a very difficult thing. It means that you would have to have one generator per unit. It is quite hard enough to get a good result on a generator with a varying load with low pressure and constant volts; the difficulty would be very much greater with high pressure and constant current. I cannot help thinking that all series and multiple-series and group systems for railway work, when examined, will have to go the way of similar systems for lighting. In the early days we all went through this phase. All kinds of arrangements were made in the period intermediate between the early one of 1880 and 1881 of the constant-current high-pressure line and the later low constant-pressure system. We had all these group systems, and some of them were worked with success. At Hastings, Eastbourne, Brighton, and other places thousands of electric lights were run on them, but they were all swept away as soon as we came to realise the advantages and simplicity of the constant-pressure system. I think, on examining the railway problem, it will lead us to the same conclusion. The evils of constant current are greater than the evils of constant pressure. The latter we know fairly well; the other we do not. I would like to go further, and to say that for railway working there is not such Mr. Mordey

Mr. Mordey. a thing as direct current. It does not exist in our art. Ever since that marvellous two or three days' work of Faraday, when he laid the whole foundations of the dynamo, there has been no advance in the mechanical production of direct current. Faraday's little unipolar machine, which without commutation gave a direct current at a very low pressure, practically remains where he left it. What we call direct currents now are all of them—it is perhaps a commonplace to say it—commuted alternate currents. We produce alternate currents in the generators; we transform to direct current by the commutator, and so get direct current on the line. When we get to the motors we have another commutating process to turn those direct currents into alternate currents, and we use them in the motors as alternate currents. These transforming processes involve a great deal of loss. The ability to do what we want to do is involved in alternate currents, and we may as well evolve it from them without this interesting but unnecessary double transformation process.

Professor Thompson. Professor S. P. THOMPSON: This is a contribution to the electrical side of the subject. A recent paper which was read by Mr. Mordey and Mr. Jenkin did not elicit, and possibly did not intend to elicit, very much of an electrical discussion. It may have been useful in enabling the traffic managers to see that the end of all things had not been attained by present methods of traction or of railway traffic. But here we have electrical problems before us, and it is on electrical questions alone that I propose to touch, interesting though the traffic questions are in themselves.

I concur with Mr. Mordey's view, that the time for supposing that continuous currents may be seriously employed for heavy railway work has gone by. It is obvious that those considerations which he has mentioned, in particular the very important consideration of simplicity in the overhead gear, will dominate this matter. Probably all questions of 3-phase or 2-phase will eventually disappear also in view of that very important necessity of simplification. No machine with a commutator on it has the slightest chance of surviving for the use of high railway speeds. Our cousins in Germany have seen this, but have not even suggested in all their high-speed proposals the remotest approach to a machine with a revolving commutator. The commutator, admirable invention as it was, enabling us to produce a very passable imitation of continuous currents out of a revolving piece of machinery, has its own service still to render, but not, I think, on high-speed moving motors. So that we almost come back to the view that the future in these lines lies for single-phase alternating work. That leaves us still a great field to discuss, for it involves all the questions depending upon differences of frequency, how low a frequency we shall be able to go down to in single-phase work for high-speed traffic. It involves—and it is by far the most serious consideration, to my mind, at the present moment—the whole question of single-phase motors. I do not believe that the keenest advocate of single-phase motors would say that the present stage of perfection at which they have arrived is such that they will do everything that could be desired. There is plenty of room for new departures in invention

in single-phase alternating motors. There is room for invention, for example, in economising that great draught of current that all single-phase motors hitherto devised take from the line at starting. Perhaps you will say that this applies also to continuous-current machines. Yes, but with continuous-current machines there are ways of mitigating that defect which do not, unfortunately, exist, or only exist in experimental form in single-phase machines. Professor Thompson

I would that Mr. Swinburne had given us something in the paper concerning the great advantages there obviously would be in several of his proposed systems if he could employ condensers for the purpose of providing at starting that preliminary draught of current which is inevitable if there is to be great and rapid acceleration. Many suggestions have been going about. Some were discussed before the arbitration a few months ago concerning the regulation of the current at the time of starting. It is obvious that if the train is to start rapidly with great acceleration there must be means taken to keep that acceleration as high as it possibly can be kept, otherwise we lose time. If you will think how any ordinary steam locomotive accelerates, you will see there is room there also for a great deal of invention; everything is left simply to the experience of the driver. He has a handle in front of him; he receives the signal that the train is to start; what does he do with the handle? He dare not pull it over to full steam; that would be an absurdity. He turns it on as much as he dares to do, and then he turns it a little more as the train gets up speed, and then a little more. It is purely a matter of experience and of personal judgment in the man, how fast he can cause that train to accelerate. In electrical matters it is wholly different. Assuming constant pressure, we have a constant acceleration provided we take a constant current. A man with an amperemeter in front of him has merely to look at that instrument, and if he moves his regulating handle so that the current is kept to a certain point, he will have a definite fixed amount of acceleration for that definite and fixed amount of current. I am assuming, of course, motors of a particular type of construction; but it may be done. The amperemeter will tell him exactly what he is doing, and if he has instructions to accelerate to any particular amount, he simply has to watch the instrument. But that could be done automatically or semi-automatically. One of the things discussed with ignorance in the recent arbitration was the use of automatically working rheostats for producing a semi-automatic uniform acceleration. I need not go into details now, but there was a very curious amount of ignorance displayed as to the operation of the liquid rheostats proposed by Messrs. Ganz for this purpose. The use of liquid rheostats was apparently a thing that half the people in that arbitration had never heard of. Why, it is the commonest thing all through Germany and Austria, in fact on the whole Continent, to use liquid rheostats as starting resistances for alternating motors of all sorts. They have had heaps of experience with liquid rheostats; and to hear it pretended that they were a novelty and had never been heard of before was a most extraordinary experience. I should not have thought that even engineers who were wedded to a continuous-current system would have so completely

Professor Thompson

pretended to ignore the existence of liquid rheostats as was the case in that arbitration.

There was another curious thing which forced itself upon my mind in that arbitration. Months ago, years ago, there was an idea prevalent—I do not know where it arose—that the only kind of motor that could possibly accelerate was a continuous-current motor. It used to be assumed that alternating motors of any kind would not give you sufficient acceleration. All that superstition had long ago been brushed away in the very crucial experiments made by Professor Carus-Wilson; and yet apparently nobody had ever heard of Professor Carus-Wilson or his experiments on 3-phase motors or of his diagrams of their acceleration which show how magnificently they accelerate. When one entered that Arbitration Court the idea that an alternating motor could not accelerate seemed to be a prevalent one; and it was impossible at the end of the arbitration even to get into the lawyers' heads, or even into the heads of some others who might have known better, that there was no better motor in the whole world for accelerating than a 3-phase motor. If 3-phase motors are going to be put out of court, it is because of the complication of the overhead lines; we need not, however, discuss them. We have to think about the acceleration of the single-phase motor. What we want is an improved single-phase motor with automatic or semi-automatic devices at starting, such as will enable the motor to have a uniform and maximum acceleration, an acceleration as great as can be permitted on the rolling stock and lines in question.

I have talked about "continuous" currents; my friend, Mr. Mordey, talked about "direct" currents, and I think he said he preferred the word "direct" because direct currents were not always continuous. I prefer the word "continuous" because continuous currents are not always direct. There are systems supplied indirectly by the current being first of all pumped into accumulators and then *indirectly* supplied out of those accumulators. There are systems supplied indirectly also, as at Oxford, by the current being put into a converter which gives out another current and not the one which was put into it, and therefore is an indirect contrivance. However, that is a matter of phraseology, and I do not wish to push it too far.

Among the curious arrangements that have been suggested for working electrical locomotives, I do not think there is one more interesting than that singular combination spoken of as the Ward-Leonard arrangement; but really, after all, if you are going to carry a whole sub-station of transforming gear on your locomotive in order to make the locomotive work with currents that are not the right ones to be supplied to it, you may as well go back to the idea originated some years ago in France, when M. Heilmann proposed to put on board his locomotive engine not a sub-station but a central station, the boiler, the Willans engine and the generator all complete, and so generate on board the locomotive electric currents which were then to be supplied to the motors on the axles. It was hardly more complicated than some of those round-about contrivances which Messrs. Swinburne and Cooper have suggested for doing that which

ought to be done simply and directly. I do not think we shall arrive at that simple and direct system of driving until we have proceeded to that stage of further invention which I have suggested, namely, the perfection, the much-needed perfection, of the single-phase motor. Professor Thompson.

Mr. C. W. S. CRAWLEY: Although I have a considerable commercial interest in alternate-current induction motors, I am by no means an advocate for using them for traction purposes. In most cases, in fact, I think that, as they exist to-day, they are about the most unsuitable means of driving trains that could be found; unless, indeed, they are used as Mr. Mordey suggests. Mr. Swinburne, however, raised a point against them which I think is incorrect. He says that the return of power to the line may be ignored because the current returned has a power-factor of only 0·7. This may be quite true; but accepting the figure, it only means that for every two amperes of watty current that is returned to line, you return in addition about one ampere of wattless current. But it takes practically no energy to produce this wattless current; you are simply returning the full value of your braking power to line as watty current, and you are returning in addition about one-half more current which is wattless. This is nothing serious. Mr. Crawley.

Professor C. A. CARUS-WILSON: A few months ago I had the opportunity, when in Italy, of seeing something of the introduction of electricity on to the steam railways of that country. As every one is aware, the two great railway companies in Italy, which between them work nearly the whole of the railways there, are carrying out electric experiments on a large scale. One of the companies has already equipped 66 miles of line with a three-phase system, and the other is now completing the equipment of 80 miles of line with the ordinary continuous-current and third-rail system. In common with many people, I had hoped that these experiments might have given a solution of, at any rate, one of the questions raised in this paper, that, namely, of the relative merits of continuous and three-phase current systems for railway work. I must say I was much disappointed, as I found that the three-phase system on the Lecco-Colico railway was working under the same disadvantages which so seriously handicapped the Burgdorf-Thun Railway, namely, excessive grades. Presumably in order to meet these grades the engineers had gone in for the Ganz system of tandem control. It seemed to me that this system was unfitted for polyphase railways generally, and that the Ganz people must have been anxious to get it into practical use in view of events which were pending in this country. For this reason I am afraid that the experiments now being made in Italy will not go far towards solving the question of the relative merits of continuous and three-phase currents for the practical conversion of steam lines to electrical haulage. Prof. Carus-Wilson.

There is therefore something not altogether unreasonable in the attitude which the authors of the paper have taken up, when they say that the whole question at the present time is more or less open. When, however, the authors state that they "treat the electric railway as if it were a completely new problem in which nothing had been done," I understand they do not intend to say more than that they

Prof. Carus-Wilson.

make this assumption as a basis on which to write their paper. Of course it would not be correct to say that the direct-current constant-pressure system with third rail is not a perfectly satisfactory system when worked in combination with three-phase transmission and rotary converters: this is proved, in one instance at least, by what is now being done on the 80 miles of line in Italy above referred to. I think we should be careful not to let the impression get about that electrical engineers were dissatisfied with this system and had no other proved system to offer in its place.

At the end of the paper, which the authors have styled "Problems of Electric Railways," it is stated that "the main problem of electric railways is to get varying speed from constant pressure." The paper recently read before the Institution of Civil Engineers by Messrs. Mordey and Jenkin was based on the same idea, showing that the minds of engineers are impressed with the necessity for some form of variable speed-gear, and the benefit such an arrangement would bring. We are, however, liable to overlook the fact that we have in the direct-current series-wound motor the precise equivalent of a variable speed-gear.

When the series-wound motor was first introduced for railway work one heard a great deal about the advantages of series winding; we were going to get a range of torque per ampere between half load and full load of 100 to 200. Such an arrangement is practically a variable speed-gear. Anything that will give us a variation in the torque per ampere is the exact equivalent of a variable speed-gear, and when we have a series-wound direct-current motor which gives us twice the torque per ampere at full load that it does at half load, this is equivalent to a speed-gear with a variation of 2 to 1. In view of the fact that every one admits what a very valuable feature this is in a motor, it is interesting to trace the development that has taken place in recent times in the design of railway motors in this particular. If one examines the motors that have been turned out from time to time by the leading makers, one finds that the range of torque per ampere between half load and full load has gradually been deteriorating, and so far now from being 100 to 200, the motors turned out by most of the best makers do not give a range of more than about 100 to 130, though some types have a higher range than this. It would take too much time to enter fully now into the reason for this, but it is due to the attempt to design a motor which will run sparklessly with very light weight. On this account the makers have been sacrificing, more and more every year, the feature of a large range of torque per ampere, and the American makers, who are often in advance in these matters, are no better than the British and Continental makers in this respect. Figure 5, which has been referred to in the paper, illustrates this point very well, as the range of torque per ampere can be easily seen. Full speed is about 30 miles an hour with 300 amperes. The rheostat is all out on the parallel notch when the car is running at 20 miles an hour with 700 amperes, so that the range of torque per ampere between these currents is 100 to 150.

Now, if a variable speed-gear is really of such great advantage here

Prof. Carus-Wilson.

is one of the very first ways in which it can be done, by increasing the range of torgue per ampere. The question is, Why is it not done? At the present moment the General Electric, the Westinghouse, and other large companies, are putting motors on our tubes and other lines in which the torque range does not exceed perhaps 100 to 130 from the half to full load, whereas if they chose to build a heavier motor they could get a range of 100 to 200, and so get a variable speed ratio of that amount. If the makers thought it worth while to turn out a motor with a bigger variable gear ratio equivalent they could do so, but they do not think it worth while because it means a heavier motor and greater expense. Before any of these new schemes are tried as the authors suggest, very largely with a view to getting the equivalent of a variable gear ratio, we shall see an attempt made to improve the design of the continuous-current motor. The Ward-Leonard system has been alluded to in the paper. Referring to the diagram Figure A, suppose that *o a b d e f* represents the current-curve, and *o g h* the speed-curve of two ordinary series-wound motors when accelerating. When the starting rheostat is all out, *k e* is the value of the current which is being used in accelerating the car at the speed *k g* plus the frictional resistance. What we are told is that the Ward-Leonard system is going to reduce the value of the current *k e*, and enable us to start up with a smaller current. But the whole of this current at this point is being usefully employed in accelerating, and no system has been or ever will be invented that will enable us to do with less than this current if we wish to accelerate at the same rate up to the same speed. Hence, the Ward-Leonard system cannot take less than this, but it will take more, in proportion to the increase of weight required for the motor generator, etc., and the lower efficiency. If the weight is increased by 12 per cent. and the efficiency decreased by 10 per cent., the current taken at starting by the Ward-Leonard system will be increased 25 per cent., as shown by the dotted line *o m*. The rheostatic heat loss with the old system is represented by the two triangles *o a b*, *b d e*; the increased heat loss in the motor with the Ward-Leonard system is represented by the triangle *o m e*, which in this case is half the former rheostatic loss; the energy thus saved is insignificant on a run of any length, and the current required to start is actually increased.

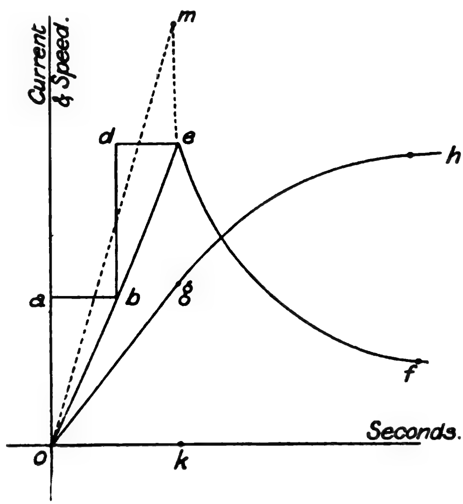


Fig. A.

Mr. McMahon.

Mr. P. V. McMahon: Much attention has been given to the question of rapid acceleration both in this paper and in the other paper to which reference has been made. I think most of the speakers have neglected to consider at what cost they are getting that increased acceleration. If we take the cost of electric energy required to obtain the results shown on diagram No. 5 and compare the curves which were published when that railway was opened,[1] we find that the starting currents under the old conditions varied between 140 and 150 amperes, whereas now, to get these results, you have to take a current of from 700 to 800 amperes from the line. In the paper the authors give the Board of Trade units per ton-mile as 0·110 at 12·5 miles an hour, and under the new conditions 0·137 units per ton-mile at 19·5 miles an hour average speed. That gives a saving in time of 36 per cent., with an increase in the units consumed of only 24½ per cent. From the results obtained elsewhere, 110 Board of Trade units per ton-mile seems exceedingly high, and would tend to show that the original motors were not properly suited to the work—that is, that they had too small a torque per ampere. On the City and South London Railway the units per ton-mile on board the locomotive are 0·055 at an average speed of 16·75 miles per hour, just half of what the authors give as the conditions on the Liverpool Overhead Railway at a much lower average speed; and one cannot help thinking there must be some error in the figures, or perhaps the units are given at the switchboard. In a paper that I had the honour of reading before this Institution some time ago, I dealt with the question of very rapid acceleration, and showed that when we were considering the re-equipment of some locomotives we ascertained what could be obtained with an ordinary two-motor equipment and also with a four-motor equipment; that was practically doubling the number of motors on a train, the total weight remaining the same. We found that taking an average section as about 2,700 ft., and the train and locomotive at 49 tons, with two motors in a locomotive, not allowing the locomotive to coast, and keeping the current on until the brakes were applied, the kilowatts per ton-mile were 0·0659, and the time taken to run the section was 122 seconds, with a maximum starting current of 300 amperes. Using four similar motors, we found that the time could be reduced to 103 seconds, but the k.w.-hours per ton-mile were increased from 0·6059 to 0·0745, while the maximum current taken when the motors were placed in parallel was 600. The effect of this on the generating station with a line of, say, 10 such sections, allowing 10 seconds at each station for stopping, and 30 trains leaving the terminus per hour, would be that the two-motor equipment would necessitate a maximum demand from the power-house of 2,085 amperes, while with the four-motor equipment 4,300 amperes would be required. The time for the journey would be reduced from 21·8 minutes to 18·67 minutes—that is, you would get a saving of 14·3 per cent. in time, but you would have to enlarge the output from the power-house by 63 per cent. Not only that, but the kilowatts per ton-mile in the case of the four-motor equipment would be

[1] Parker on "Electric Equipment of Liverpool Overhead Railway," *Proc. Inst. C. E.*, vol. cxvii., p. 30.

increased by 13·5 per cent. The authors referred to what might be done on the Central London Railway, and allow an increase of 25 per cent. in coal for the increase of 50 per cent. in speed maintained for four hours per day, and this figure also includes an allowance for the working of lifts. As the increased speed would have to be obtained by very rapid acceleration, I consider the extra for coal, generating plant, etc., far too little, and this is borne out by the figures given above and the following. Mr. McMahon.

On page 987 of the paper they refer to the value of rapid acceleration, and show that in one particular instance the time for running a certain section was reduced from 104 seconds to 68—that is, a saving of 36·4 per cent. of time, or less than they would hope to see on the Central London; but the energy consumed increased from 330 to 1,390 k.w., or an increase of 320 per cent. The current for the lifts would also go up in somewhat the same ratio.

I agree with some of the speakers who said that if we were to have these high rates of acceleration it would require some sort of a variable speed ratio-gear, and also the absolute necessity of returning current to the line in bringing the train to rest in the station. I think Professor Carus-Wilson is right in saying that the well-designed series-motor is about as good a thing as we know at present for traction. But, unfortunately, in the series-motor the traction force per ampere rapidly diminishes as the speed increases; and if you want to maintain the acceleration, you have to shunt the field or adopt some other device.

In another part of the paper the authors give us as an alternative to increasing the speed, the reduction in the number of carriages in a train in the middle of the day. In tube railways I am afraid that is difficult to arrange. The amount of shunting that it involves in dividing trains up in the sidings wastes more coal than suffices to neutralise the actual saving obtained by such an arrangement. In fact, some five or six years ago on the City and South London Railway we had some 2-coach trains and some 3-coach trains, the idea being to run 2-coach trains in the middle of the day on the light load. We found that our coal bill was just as high when running with 2-coach trains in the middle of the day, on account of the amount of shunting that had to be done to get the trains out of long sidings. It is not as if you were out in the open where your sidings branch out in a fan-like arrangement; you have to store the trains one after another. Of course the multiple unit system gets rid of some of these disadvantages; but it yet remains to be seen whether this system is better than separate for tunnel work.

In diagram 7 the starting period, as shown, bears a very large relation to the total period of running, and gives one the idea that the series-parallel controller is about the most uneconomical thing you could have. But taking the curves for actual section, as run on the tube railway, I think it will be found that the starting period would be shortened to about one-half of what it is shown on the diagram. Some time ago I went carefully into the question of losses in a series-parallel controller used in connection with motors designed with a high torque per ampere, and found that it varied between 10 and about 14 per cent.

Mr. McMahon.

of the total energy used in starting the train, *i.e.*, the energy taken from the line from the time of switching on until the train attained full speed, and as this represents about half the energy for running the section, the losses may be taken as from 5 to 7 per cent. of the total. If the driver will not keep his eye on the ammeter and maintain his current constant at the proper starting value by cutting out the resistance until its value drops of its own accord, due to the rising back E.M.F., the loss may be several times as great as stated above. For this reason, I think if the automatic arrangement or semi-automatic arrangement which Professor Thompson describes would work well in practice, it would be a very acceptable thing to those who have anything to do with drivers who work series-parallel controllers—in fact, it would take the regulation out of their hands altogether.

With reference to the constant-current system as advocated by the authors for suburban lines, or even main lines, I think that as far as can be seen a great deal of trouble would be experienced with the switches when you changed from one side of the system to another. In a time of busy traffic, I am afraid I would not like to be the engineer who was responsible for the satisfactory working of the switches. One of the reasons advanced by the authors for the series system was that you can get rid of the waste in the controller and complicated switch-gear. With the switch necessary for shunting the field of the series-motor to vary the torque and the short-circuiting devices, it seems to me that the switching gear that you would require for this locomotive would come out nearly as complicated as the present series-parallel controller.

There was one other point referred to by Mr. Mordey, namely, the difficulty of maintaining a steady current with a varying voltage. It might act very well on an arc-lighting machine, but when you come to deal with very large powers, I am afraid you would have great difficulties. Mr. Mordey laid particular stress on the generator difficulty. I think you would also have considerable difficulty with the engine. An engine of, say, 2,000 k.w. capacity would not respond very quickly to the sudden call upon it for a variation in its speed which a couple of trains starting at once would demand. I do not feel certain, but consider that in a steam engine working under the above conditions the steam consumed per kilowatt would be very high.

The third advantage that they claim for the system is constant torque at all speeds. This is a very important item, and to me seems to be about the only real advantage that can be claimed for the system. There is one other point; they allow a maximum pressure of 2,000 volts per locomotive. On a line with 25 such locomotives you may at any time get a maximum pressure of 50,000 volts between the switchgear and cab, which would be earthed on one locomotive, and assuming an earth on one of the conductors, considerable difficulty would arise with insulation. I know with 500 volts on board a locomotive the insulation is very often hard enough to maintain.

Towards the end of the paper, on p. 1006, the authors allude to the want of regulation, or the inability on several systems to make up for lost time. In an ordinary locomotive with two motors, in the case of

the tube railways, if a driver is checked by a signal he simply shuts off his current when he sights the signal, and lets the locomotive coast for a while until the signal is taken off; and if he wants to make up time, he keeps his current on a little longer and stops sharper at stations—in fact, he has the same means of making up time as the driver of a steam locomotive. Mr. McMahon.

Mr. W. GEIPEL: I am very much indebted to the authors for bringing this subject before us. It is one which deserves the very serious consideration of the electrical engineering profession at the present time. I am not one of those who believe that the application of electric traction to the working of long lines is in the dim and distant future. I think that the time is very near at hand when it will be seriously considered by the large railways running long-distance lines. One point which has particularly struck me in the paper is this, that the authors recommend three different systems for operating railways. For suburban lines they recommend constant currents; for shunting purposes they recommend secondary batteries or the present system of steam locomotives; and for long main lines, on p. 1006 I see they recommend the parallel system. I differ with the authors entirely in this respect. It appears to me that the system which is adopted for working the suburban traffic should be the system to be adopted for working the main-line traffic and for shunting. Further than that, it is of very great importance, not only to railway companies but to the electrical engineering profession, that the system which is adopted should if possible be a system common to the whole of the railways of the United Kingdom. If each railway adopts the same system, the trains will be interchangeable; they will be able to run from the one line to the other, and the advantages generally will be enormous. For that reason, at the present moment, too much attention and discussion cannot be devoted to this important subject. Mr. Geipel

There are two paramount considerations to be borne in mind. The first, that of frequency, has been referred to by the authors, and the second I think they have not referred to, namely, the question of high pressure and of working pressure. It has been suggested by Messrs. Mordey and Jenkin in their paper that a frequency of 40 should be adopted having regard to the consideration of the lighting of the railway carriages. I mention this to show that there are different opinions on this important subject, and therefore that it is one which should be thoroughly considered at the present time. My own view is that a periodicity of 40 is very much too high for the working of railways, and that the recommendations of the Institution of Electrical Engineers as to the frequency for power purposes, namely, that of 25, is nearer the requirements of the case. After all, the lighting requires a mere iota of the total power, and the lighting can be arranged, whether the frequency is low or high, in many obvious ways. Then with regard to the pressure, I think it is also important that we should have one extra-high pressure, either 10,000, 15,000, or 20,000 volts, or some other even number at any rate. I see that in one scheme recently proposed 11,000 volts were to be adopted.

Coming to the paper, on page 973 the authors point out that the

Mr. Geipel. steam locomotive gives a great torque at starting. I always understood that one of the advantages of electrical working over steam working was the enormous increase in the torque in accelerating our trains. The torque of a locomotive is, on the contrary, bad; it is always the same. You cannot get a large torque out of a locomotive; it is limited by the pressure of steam on to the area of the piston and it is also controlled by the position of the crank. Further than that, the uneven turning moment which accrues results in a tendency to skid, which you do not get with the electric motor; consequently you have a very much larger torque with the electric motor than you have with the steam locomotive. I do not quite agree with the authors that motors will give any torque required at great expense of power. That does not follow at all. A motor will give large torque without great loss of power provided the power is supplied at such a voltage as is suitable to its speed. Of course if you use a source of power where the voltage is reduced by needless resistances, then that particular motor is working under uneconomical conditions, but not necessarily so if other arrangements are made.

With regard to acceleration, I have been much struck this evening by the fact that so many speakers with the authors consider that the acceleration should be constant, and that there should be a constant torque throughout the period of acceleration for that reason. I have been under the impression that it was very important that the comfort of the passengers should be considered where you come to high rates of acceleration, although for low acceleration it is not a question of great importance. I have understood that the consideration from that point of view is that the rate of change of acceleration is that which should be constant, not the acceleration itself. If you look at the curve in Fig. 2 you will see that you have a constant acceleration from nothing up to full speed; you suddenly jerk your passengers into motion, and you suddenly jerk them from rapid acceleration into a continuous speed, which is most uncomfortable to say the least of it. Those who have ridden in high-power motor-cars find that very much accentuated. If your engine is governed and you are accelerating up to a high speed, as soon as the car is running at the speed at which the engine is governed the acceleration suddenly ceases and you are shot forward immediately. It is a most uncomfortable feeling, and one which I think passengers would decidedly object to.

There are a number of points with regard to the advantages and disadvantages which the authors refer to in their system, which I will pass over briefly. I would suggest that one particular disadvantage which they have omitted is the danger to attendants on the locomotive. The double conductors, they say, do not constitute a vital objection, but I should suggest that more particularly at the points and in the case of high speed they are a very vital objection, and I quite agree with Mr. Mordey that the overhead wire should be "simple and single." The difficulties with the generators and extensions of the stations and general want of flexibility in the generating plant, have been already referred to by Mr. Mordey, with whom I quite agree so far as concerns the system recommended by the authors. Then again,

current is not easily diverted for other purposes, for the working of auxiliary engines, cranes, lifts, and so forth; and it is not so easy to call in the aid of local power-stations. It is not at all improbable that long railways might find it convenient at times to buy their energy from the local or district electrical power-stations, in which case it is important that they should use some system which would enable them to do it. As to the advantages claimed for the constant-current system by the authors, I have referred to one, namely, constant torque, which appears to me to be a disadvantage. Then there is the collection of current, which the authors say is simpler than with the usual parallel system, but they will have the difficulty of the two wires in collecting. Mr. Geipel.

I should have liked to make a few remarks about the Ward-Leonard system, but will only point out one thing in connection with that system, namely, with reference to the curve of Professor Carus-Wilson. He referred to the waste of energy in one particular point of the curve during acceleration, but he has neglected the other points where the energy is wasted in controlling resistances. The curve he has shown indicates that there is a sudden jump from nothing up to the full current, then a rest, and then a sudden jump again up to full current: I presume that is when you switch from series to parallel, or *vice versâ*. I would point out that in the use of the Ward-Leonard system you convert your energy into current at a voltage which is exactly suited to the voltage of the motors at the speed at which they are running at the moment. That is a point which he has omitted to take notice of. There are many advantages in this system which have been referred to by many speakers. I will briefly point them out; their beauty of control, the gradual increase of the rate of acceleration and of retardation in such a way that it is not felt by the passengers. That has been appreciated in the case of high-speed lifts in America, where the Ward-Leonard system is being used in that connection; and although the Ward-Leonard system has not been applied to railway working yet, the gradual change from the state of rest to motion, and from the state of varying motion to the state of continuous motion, has been very much appreciated in the case of the lifts.

(*Communicated.*) With regard to claim 8 on page 999, viz., that high pressure is easier to handle with continuous than with alternating currents, I would point out that experience has shown the reverse, and that the great majority of important transmission power schemes where high tension is employed use the alternating current, and I take it that the easy handling of the continuous-current claim does not refer to the generators, where the difficulties are enormously greater.

On page 1001 the authors claim that the engines driving the generators at constant torque with variable speed would be more economical; in fact that the coal consumption would be approximately half. I do not share that opinion; on the contrary the engines would be less economical, for although the mechanical efficiency of the engine would be greater, yet the loss by initial condensation at low piston speeds would more than compensate. I might mention that according to Willans tests the percentage of initial condensation varied from five

Mr. Geipel. per cent. at full speed down to twenty per cent. at about one-fourth speed.

The authors state that an overload could not occur on the series system, for if all the trains started at once they would merely run slow until the matter righted itself. That is one of the respects in which the "Ward-Leonard" system is superior both to the series system and to the ordinary parallel system, for if all the trains were started at once the power used in starting would be less than the normal power to keep them all running. This is because Ward-Leonard converts his energy at starting into low voltage current, so that the motor part of the motor-generator takes considerably less power from the line during the earlier periods of acceleration, whereas with other systems the reverse takes place. I quite agree with what the authors say on page 1011 that the single-phase alternating system is the best form of transmission of power, but I do not agree with them as to the difficulty they anticipate in making use of the alternating current when it arrives at the train. It is merely necessary with the Ward-Leonard system to place on the locomotive a single-phase motor without regulating or controlling resistances. All that is necessary is a starting switch and a pair of high-tension fuses. This motor rotates at constant full speed and drives a continuous-current dynamo which generates current at a voltage suitable for working the motors which drive the train. Objection has been taken to the weight of this motor generator, but, after all, it is but a small percentage of the total weight of the train. For example, the weight of a 200 k.w. motor-generator would probably be about twenty tons, and if very high speed were adopted it would be less. Then this extra weight has the advantage in cases where trains are operated by locomotives, that there is an addition to the tractive power of the locomotive.

The authors refer to the cost of the Ward-Leonard system as being excessive, and while they do not give the costs of their own system, yet I have been able to compare the cost of the Ward-Leonard system with that of the ordinary system of having fixed motor-generators placed along the line and transmitting the low-voltage current from the sub-stations to the locomotives; I find that the Ward-Leonard system, on the contrary, makes a very considerable saving in cost. In the first place, it dispenses with the low-tension conductors which in the Metropolitan Railway scheme were estimated to cost between £6 and £7 per kilowatt, and in Mr. Langdon's paper they were estimated to cost £70,000 for fifty miles of railway requiring 5,000 kilowatts to operate, *i.e.*, £14 per kilowatt, or about double the cost on the Metropolitan Railway. In the case of the Ward-Leonard, the overhead high-tension conductor can be fed by static transformers at frequent points, so that it would be comparatively very small, and would cost but a small fraction of the two low-tension conductors. Further, in the case of fixed motor-generators it is necessary to make provision for a concentration of traffic at varying points of the line, so that the sub-station plant is considerably greater than would be necessary if the trains were always equally distributed. With the Ward-Leonard system the motor-generator is on the locomotive, and it is therefore not necessary to make

such provision. Consequently the expenditure on motor-generators is less. Further, it is not necessary in the generating plant to provide for peaks in the case of the Ward-Leonard system, as there are no peaks. Here, again, there is consequently a large saving made in the capital outlay. In putting the saving—by using the Ward-Leonard system instead of the continuous motor-generator system—at £15 per kilowatt, I believe I am underestimating it, and I do not therefore agree with the objection of the authors that the cost is prohibitive. Then with regard to the cost of working, attendants at the sub-stations would be dispensed with, the attendants on the locomotives would do all that was necessary in the starting up and running of the motor-generators. Then there is a great economy of power in starting and accelerating the trains, while the power lost in the motor-generators occurs only at the points where the locomotives are used, and not all along the line as in the case of fixed motor-generators. There is a further saving of the wear and tear which takes place in the heavy switches and resistances which are dispensed with on the Ward-Leonard system. **Mr. Geipel.**

The authors suggest some sort of mechanical friction coupling for transmitting the power from the alternating motor to the axle of the locomotive. I cannot imagine any sort of mechanical friction coupling which would compare in any respect with the Ward-Leonard, which is, after all, an electrical coupling, nor do I think it would be practicable to design a mechanical friction coupling which would give the desired varying speeds and at the same time transmit the large power required. Even in the motor-car industry, where the power is but a fraction of that required for a train, there is no satisfactory mechanical friction coupling with variable speed; it is consequently necessary to resort to toothed wheels, or other such devices.

Professor Thompson has referred to the complication of the motor-generator on the locomotive, and went so far as to say that we may as well put the steam engine and generator on the locomotive. I do not agree with him; 100 tons is one thing and 20 tons another, and as to the complications, I think I have already shown that they are a myth. In fact, I am of opinion that there is less complication with the motor-generator on the locomotive than with the complicated resistances and switches which are required with the present series-parallel system, more especially if those resistances were designed so as to make the locomotives suitable not only for running at high speeds, but also for running for long periods at slow speeds for shunting and other such purposes; that is a difficulty which has been found to exist in the case of railways like the Central London, where the regulating resistances will not stand shunting, while to enable them to do so it would be necessary to increase and complicate them largely.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:— **The President.**

Members:

Sir Douglas Fox.	Arthur Lazenby.

Associate Members:

Chas. Albert Blascheck.	Fredk. Joseph Mars.
Joseph Bernard Clarke.	Henry John Robertson.
Chas. Garnett.	Geo. Fredk. Whipple.
George Jas. Gibbs.	Wm. Arthur Wilkinson.

Associates:

James Bennett Bingham.	Alan McAlpin.
Joseph Percival Crowther.	Edwin Albert Mansfield.

Students:

Christopher Dalley.	Fredk. Vernon Harrap.
Cuthbert John Greene.	Edward Pink.

Geo. Augustus Tucker.

The Three Hundred and Seventy-Seventh Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 24, 1902, Mr. W. E. LANGDON, President, in the Chair.

The Minutes of the Ordinary General Meeting held on April 10, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

William Aitken.	John Pilling.

From the class of Associates to that of Associate Members—

Comer Sandys Ball.	George Robinson Peers.
Willie Dickson Kilroy.	James Scott Pringle.
Gustavus McAlpine.	Frederick Charles Stephens.

From the class of Students to that of Associates—

Hilary Henry Dadson.	John Thomas Irwin.
Evelyn Fawssett.	Lawrence J. Kettle.
Ramon I. Fernandez.	Charles Noel Moberly.
Francis Wm. Hewitt.	Charles Trimnell.

Messrs. W. Henderson and D. H. Slack were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from The International Engineering Congress, Glasgow, Maschinenfabrik, Oerlikon, and Dr. Henry Wilde; to the *Building Fund* from Messrs. F. W. Clements, F. H. Goodall, and J. Maclean; and to the *Benevolent Fund* from Mr. G. J. Gibbs; to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have now to announce the Council's nomination of officers for the ensuing Session :—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE IN 1902–1903.

As President.

Nomination. JAMES SWINBURNE.

As Vice-Presidents (4).

Remaining in Office. MAJOR P. CARDEW. S. Z. DE FERRANTI. JOHN GAVEY.

New Nomination. PROFESSOR O. LODGE, F.R.S.

Ordinary Members of Council (15).

Remaining in Office.	H. H. CUNYNGHAME, C. B. HUGO HIRST. J. E. KINGSBURY. C. P. SPARKS. H. E. HARRISON. Lt.-Col. H. C. L. HOLDEN, R.A., F.R.S. The Hon. C. A. PARSONS, F.R.S. W. H. PATCHELL. J. H. RIDER. MARK ROBINSON.
New Nominations.	Sir JOHN WOLFE BARRY, K.C.B., F.R.S. B. DRAKE. S. DOBSON. R. KAYE GRAY. A. A. CAMPBELL SWINTON.

Associate Members of Council (3).

Remaining in Office.	W. R. COOPER. W. DUDDELL.
New Nomination.	SYDNEY MORSE.

As Honorary Auditors.

For Re-Election.	F. C. DANVERS.
New Nomination.	SIDNEY SHARP.

As Honorary Treasurer.

For Re-Election. Prof. W. E. AYRTON, F.R.S. (Past President).

As Honorary Solicitors.

For Re-Election. Messrs. WILSON, BRISTOWS & CARPMAEL.

RESUMED DISCUSSION OF MR. SWINBURNE'S AND MR. COOPER'S PAPER ON "PROBLEMS OF ELECTRIC RAILWAYS."

Mr. Shoolbred.

Mr. J. N. SHOOLBRED: I have been much struck by the oft-repeated statement during the discussion, "that we were not yet ripe for the application of electricity to long lines," and this made in a sort of despairing tone—as if we are to remain idle, and do nothing towards preparing, and making smooth the way for the time, when we shall be called upon to attack the "long-lines" problem. Statements of this kind referred to appear to arise from not realising the enormous importance of the movement going on at present throughout the land, which is to endeavour to devise a *general* system of transportation, *actuated throughout by electricity;* and which shall include the various means of conveyance known as railways, light railways, tramways, etc.—whether they be fast, moderate, or slow in their respective action—and which are engaged in what the President has happily termed, "Conveying and collecting traffic." To ensure this generalising of the means of transport the keynote is *uniformity* in the various parts. To arrive at this uniformity, there is a vast deal of

preliminary work to be done—and much of it is dependent upon common business considerations—quite irrespective of technical knowledge; and which comes quite within the province of most of us. Take, for instance, the gauge of the vehicles to be used. Railways had to pass through "the battle of the gauges" before they were compelled by dire necessity to adopt the present uniform gauge. It is only just beginning to dawn upon those who control the vehicles of the other classes, such as tramways and light railways, that if they are to form part of the general system—and reap to the full the benefits of inter-communication—and at the same time form useful adjuncts, or collectors of traffic, to the large railways, the gauge of their vehicles must be similar to that of the railways. Mr. Shoolbred

Some of the more important County Councils in the country are already doing very useful work towards arriving at this uniformity by insisting upon the adoption of the 4 feet 8½-inch gauge.

Again, uniformity in electric pressure is another matter of paramount importance. But it is by attempting this combined action of the various tramways, or light railways, which at present form but disjointed electrical units, that we shall find out which is the fittest electrical pressure, and the one best suited for *general* use. In doing this, simplicity of working arrangements will certainly form a most important factor.

The experience of the last twenty years—as far as electric lighting is concerned—tells us that the key lies in simplicity; which also means economy. The very large alteration in the character of the plant in some of the most important electric-lighting stations in the Metropolis, and elsewhere, from high-pressure alternating to low-pressure direct, points to a decided advantage for the "direct" current. And that same simplicity in working will weigh even more in a traction system, where several different carrying lines have to work together.

The difficulty of long distance transmission with "direct" currents, which is always raised against them (and which is mainly a matter of durability of insulation resistance) cannot always continue. Indeed, many ingenious expedients are already being introduced (take, for instance, those of Mr. McMahon, on the "City and South London" Railway) by which the difficulty of long-distance transmission is being gradually overcome.

In conclusion, I would say, that there are many small ways by which we can assist in trying to arrive at the much-wished-for combined action of our various methods of locomotion. And it is in these attempts, humble and unpretending though they may be, that much progress can be made in solving the problem of the use of electricity on long lines of railway.

Thus many of us can assist greatly in the solution of what may be termed the "national" problem of elecfric locomotion, towards which problem the present paper does much in elucidating its higher and more technical aspects.

Mr. W. P. Digby: I cannot agree with the author of this paper, nor with the last speaker at our last meeting in their unanimous desire for standardised conditions of working in electric railway work. The only heritages from the steam railways in England Mr. Digby.

Mr. Digby. to-day which will come to us are the heritages of the gauge and the height above rail level. The authors acknowledge that the question of express and goods traffic is not ready for tackling. Therefore as the traffic which mnst first be dealt with will be of the suburban nature, would it not be best that each of those systems should be developed according to the individual needs of the case, perhaps even according to the prevailing method of electric supply in the different districts? In Great Britain the steam locomotive has not been standardised in regard to its height, wheel base, load pressure, or stroke, and yet without any standardisation the result has been the English engines of which English engineers are so proud. It may be urged that the engines are interchangeable, that the North-Eastern Railway engines might run into King's Cross instead of giving place to a Great Northern Railway engine at York. For administration purposes this is not done. Similarly, the rolling stock of the City of Newcastle does not find its way by any chance among the rolling stock of the suburban lines of London. On many main lines different steam locomotives are used for different work, even for different express passenger work. The suburban traffic is distinct from those conditions, and while a universally standardised state of railways might be good on one side, I think it would be better if each surburban system developed according to the local conditions, and even according to the views of consulting engineers who were employed in the matter. So long as the electrical locomotive is employed there will be, to my mind, no necessity for a universal standardisation. At any station where the locomotive of one company gives place to the locomotive of another company the three-phase motor might give place to a locomotive driven by continuous current motors. Neither of the talented authors of this paper would claim that the problems they have enunciated here are all the problems which will have to be faced, nor would they say that the plans they favour are certain in ten years time to be recognised as the universal necessity in the country. Under these conditions, I think we are laying too much emphasis on the question of a universal standardisation. When all the railways of the country are in the hands either of the State or of some American millionaire combination, then will be the day to consider the universal system of electric traction. With regard to the series continuous-current system proposed, I think Messrs. Swinburne and Cooper have rather hastily assumed that a pressure of 2,000 volts will be adopted. If only the Board of Trade will accept the reasons they have stated in the paper without further quibble we might perhaps have such a pressure. Nevertheless, in regard to distribution, the question would arise as to whether the leakage from the third rail to earth—a leakage which one does not find in the tube railway—would not be a serious factor with the rails exposed to the vicissitudes of an English climate. This appears to be a special objection to the series constant-current system, with a length of conductor double that required for a constant-pressure system.

Mr. McMahon. Mr. P. V. McMahon: The accompanying diagram arises out of Professor Carus-Wilson's remarks on the last occasion. It affords a comparison between the Ward-Leonard and the series-parallel

systems. The curves show the effect of an ordinary locomotive with two motors, the same locomotive fitted with the Ward-Leonard system, and also an equipment of four motors of the same size retaining the same total weight of train. The curve A represents the speed in miles per hour for the locomotive with two motors, the motors alone weighing eight tons. The current taken from the line is shown by A′, the locomotive being controlled by a series-parallel controller. Professor Carus-Wilson pointed out that by drawing a line from the point where the maximum current begins to drop to the origin of the curve you get loss in the controller. He then drew another line above the series-parallel loss curve showing that the loss in the Ward-Leonard Mr. McMahon.

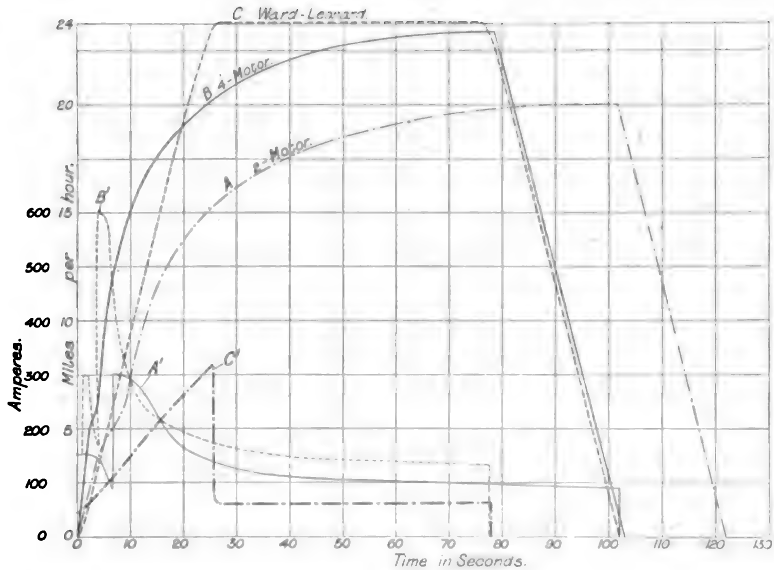


FIG. B.—The curves A and A′ refer to the speed and current for a 2-motor equipment, B and B′ to a 4-motor equipment, and C and C′ to the Ward Leonard arrangement.

system was not different, but greater in amount. He neglected, however, to say that a very much better speed curve is obtained for the same energy transformed by the use of the Ward-Leonard system. In the diagram, I have taken a short section of 2,700 feet, with a train of 49 tons, which is the total weight of a locomotive and train on the City and South London Railway. For the Ward-Leonard diagram I have assumed two of the existing motors shunt-wound, and a Ward-Leonard combination added to the locomotive which will weigh perhaps another four tons—that is, about the weight of one motor. The motor generator will not weigh more than one motor, because the speed will be much higher. Instead of 150 amperes at starting we take about 45, which rises gradually to the maximum allowable current. It will be noticed that the speed curve shows that

Mr. McMahon.

we get uniform acceleration. I have limited the maximum current to 300 amperes for the 2-motor equipment and Ward-Leonard arrangement. In this case it is 318, but as 318 comes in better for calculation, I reckoned it on that figure. The curve C' shows the gradual rise of current from 45 to 318 amperes. When you finish your acceleration you alter the fields of the generator, and the current immediately drops from 318 to 59 amperes. It remains a constant quantity until you shut off the current and apply the brakes. Of course you would not apply them so sharply as that in practice, but it saves calculation to show it in the diagram. You will see from curve C that about twenty seconds are saved on the run as compared with the 2-motor series-parallel arrangements. With two motors it takes 105·4 watt hours to run the section; with the Ward-Leonard system it comes out absolutely the same, 105, but there is a difference of twenty seconds saved in the trip.

Coming to the same train fitted with four motors, they are the same motors exactly as in the first instance, and can be arranged on the one locomotive or distributed through the train. You start with 150 amperes with the four motors in series; when you reach a speed of two miles an hour you put them two in parallel, two in series, and finally the four motors in parallel, when you get a maximum of 600 amperes. You get a higher acceleration at starting than in either of the other cases, but on account of the rising back E.M.F., you are not able to keep the acceleration constant, and in consequence the speed curve drops over, but it just happens to run the journey in the same time as the Ward-Leonard arrangement with the maximum of 318 amperes that you start with. This arrangement of four motors is more economical in energy, the watt-hours being only 98·6 as against 105. As against that you have to provide a generating station that will give 600 amperes instead of 318. If you are satisfied with a speed curve drooping over as in the case of the series-parallel system from the Ward-Leonard, you could considerably reduce the starting current, in fact from some rough calculations of mine it appears that if you cut your starting current down to the running current, *i.e.*, the current would never exceed 120 amperes and you would get the same result as in the case of the series-parallel arrangement. The more one looks into the question of the Ward-Leonard or some other system which gives a variable speed ratio at starting, the more one sees there is a great deal in it, and when one comes to employ alternating currents direct, and one can drive the generator and the locomotive with the alternating current motor and do away with the substation as suggested by Messrs. Mordey and Jenkin, it will have a great many advantages over the present arrangements unless something better arrives in the meantime. In calculating this curve I may say that I had not all the data at my disposal connected with the Ward-Leonard system, but I assumed that the combination had an efficiency of 93 per cent. Probably some people will say that is high, but only a half of the energy is transformed. The booster on the locomotive is employed in the first part of the starting to oppose the 500 volts, and when you get up to the maximum pressure you reverse the generator and booster up to 1,000, so that you really

only transform half the energy. The regulating or starting gear of the system is very simple. It is impossible to get the irregularity of starting that you do with the series-parallel controller. Through the courtesy of Messrs. Geipel and Lange I was able to watch a large (50 unit) plant operating a printing press on this system, and the control the attendant had over machinery was marvellous. He could make the press run at any speed from crawling slowly to full speed for any period without the slightest jerking. If it was applied to a locomotive or to any kind of traction motor I think it would turn out satisfactorily. Mr. McMahon.

Mr. A. A. CAMPBELL SWINTON: I was rather struck with what Mr. Swinburne has said as regards uniformity. I have recently had brought to my notice an instance, showing the importance of this question. I have been attending the Committee that is sitting in the House of Lords on the subject of the tube railways. As we all know, the Central London Railway works with a central insulated conductor, and uses the rails as a return. Now, on the railway which is at present before the Committee—I do not really quite know what to call it, because it began by being a comparatively small undertaking, but it has now grown to have a capital of some £15,000,000 sterling, and is a combination of the London United Railways, the Piccadilly and City, and several other railways all rolled into one—they are proposing to use an insulated return, with the two conductors, the trolley wires, if you can call them so, at the side of the track. Of course it is obvious that if that system is adopted there will in the future be great difficulty in making the rolling stock of the Central London run over that line. There are two or three more Bills still to come on, and I take it they will each probably propose a system of its own, so I think this question of uniformity is a very pressing and important matter. I fear, however, that as I heard it very aptly stated the other day, the electrification of the traffic of London is becoming merely a pawn which American millionaires and American trusts companies use to play their game. Mr. Campbell Swinton.

Mr. M. HOLROYD-SMITH: The last speaker has suggested a difficulty. I had no intention of speaking when I came here, but as I have a simple solution of the difficulty I will, with your permission, explain it to the meeting. Curiously in England and in America they will put overhead wires in the streets where they are dangerous, because there is other traffic, other wires, wind storm, snow storm, etc.; but when you go on to a railway, and you have the whole thing to yourself and a tunnel nearly the whole of the way in which you could attach, without hurting anybody, an overhead conductor, the opportunity is missed and people will persist in putting the conductor bar on the ground, generally between the two rails, as though they were deliberately designing something to be dangerous in the case of accident. It is evident that that is not quite the right thing to do. It is now proposed to put the conductor at the side as though that had not already been done. A previous speaker has informed the proposer of the side rail plan that it would be difficult to deal with at points and crossings and in regard to other traffic running over such a line. Why Mr. Holroyd-Smith.

Mr. Holroyd-Smith. not take the most simple solution you could possibly get, a solution which I arrived at some years ago, and which we shall in all probability have brought over before long as a new American scheme? That is, place the conductor or conductors overhead in this manner.

It may reasonably be assumed that whatever is the present dis-

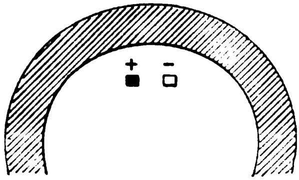


FIG. C.

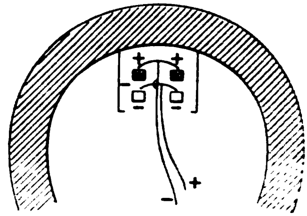


FIG. D.

position of Parliamentary Committees, it will ultimately be prohibited to use the earthed rails as a return.

Let C represent a section of a railway tunnel (Metropolitan lines are and will be mostly tunnels or tubes) and two insulated conductors be placed overhead, such an arrangement would be all right until you came to points and crossings, where, if the conductors are continuous, they would obviously short-circuit unless there were gaps in them, which would mean double collectors and abundant possibility of getting out of order.

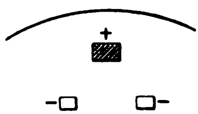


FIG. E.

Now if the arrangement shown in Fig. D be adopted, viz., place the + and — conductors in different horizontal planes, preferably two of each, then all difficulties vanish. You can have any complication you like of points and crossing without fear of short circuit, and further, the electrical points can be operated at the same time as the rail points and so prevent the train from running one way and the collector another. The collectors could be hauled along by insulated cables or a modification of the trolley bar could be used, where it would be found more convenient to have the top conductor single and the lower conductors dual, or *vice-versâ*.

Mr. Barnes. Mr. J. S. BARNES (*communicated*): This paper is opportune at the present time, inasmuch that the subject is occupying the attention of the electrical engineering profession, to a very great extent on general lines. Without doubt the utilisation of electrical energy for driving all kinds of machinery has proved itself to be very economical; the efficiency is high; and in practically every instance the system has given every satisfaction. There is no reason, to my mind, why this should not prove so on our railways if the details of the electrical engineering construction are thoroughly worked out, and the proper system is adopted for the particular route under consideration, and provided that the electrical energy is generated in large central stations, situated near to the coal centres in different parts of the country (on the lines of the proposed power-schemes which have recently received Parlia-

mentary sanction), the generating stations being so designed in the systems adopted as to secure uniformity of voltage and of gauge. Mr. Barnes.

There seems to be a difference of opinion as to whether the electrical railways shall be equipped with three-phase or continuous-current machinery on the trains themselves, but practically every engineer agrees that three-phase plant is the right kind to adopt in the central stations of these proposed railways, whenever the length of the line is such that uneconomical results may accrue from the C^2R loss in transmission of electrical energy in the main feeders. It was pointed out by Major Cardew, in the recent arbitration case of the Metropolitan and District Railways, that the electrical systems to be adopted on lines that were to be in connection with one another should be all of one kind; and that, in all such lines, the proper system to adopt was the three-phase. From an engineering point of view it is difficult to conceive why the three-phase currents should not be applied on the motors themselves, when a reasonable transformation of the electrical energy has been made.

It is a recognised fact that in an electrical tram service of any magnitude, there is a considerable demand for electrical energy the greater portion of the day, and the greater the number of the cars running the less is the fluctuation of the station generators, and the better the load-factor, which of course leads to economical working. It is very evident that this will be the case with electrical railways, except that the load on the station generators will vary considerably more, due to the heavy trains requiring considerably more energy than do individual tramcars.

The power required from the motors in producing motion of the train at the commencement, exceeds the resistance encountered between the wheels and the rails, and the speed of the train will increase (*i.e.*, the motors will accelerate) until the resistance (whether mechanical friction or wind resistance) is equal to the power exerted by the motors in propelling the train; the speed of the train will then be at the uniform maximum attainable on main-line railways. It is evident that the three-phase systems would be worked economically on long-distance runs, and will maintain a uniform speed and prove more advantageous than the continuous-current systems; but for urban short lines, with a considerable number of stations, involving stopping and starting of the train at frequent intervals of time, the continuous-current system possesses the advantage of a large variable speed and torque which is very desirable. With both the three-phase and continuous-current systems for the same amount of power required to be given out by the motors on the train, the acceleration would be equal if these systems worked under the same conditions, and the energy in watt-hours consumed per train-mile would be equal in both systems.

Mr. Sinclair Fairfax.

Mr. J. Sinclair Fairfax (*communicated*): In stating the general conditions applicable to electrical railways, the authors naturally avoid dwelling upon mechanical details. But Mr. Swinburne, in his verbal summary, laid stress on the desirability of obtaining a good variable speed-gear in connection with the subject of acceleration, at starting, especially on short urban or tube lines. Perhaps the most available

Mr. Sinclair Fairfax.

mechanical method of accelerating the starting and retarding the stopping of trains having short runs at a high speed is the well-known spring-buffer system, a system which has never yet been fully developed, for various reasons. On the principal steam railways the old-fashioned short coaches were an obstacle, and with long runs between stations, and light trains, it was unnecessary. So long as the locomotive could get sufficient tractive power to start a heavy train by first backing and compressing the buffer springs, and then leading off with practically one coach at a time for a few inches, it was sufficient. On the underground system in London, with its heavy trains and short runs, spring buffers are literally crushed out of action, for the coaches are permanently coupled up with only a few inches of space between them, in order to save platform room, the land for which involves enormous cost. But on deep-level electrical railways other conditions apply, for the extra length of platform required involves only the cost of first construction and maintenance, and with a range of several feet for each buffer, an easy method is available for accelerating and retarding the train motion.

But to get the full advantage of acceleration and retardation the electric locomotive should be abolished, and the multiple-unit system adopted to the fullest extent, now that it has been shown to be available. Electric locomotives served during the transitional period, as in the early days of lighting, gas fittings were adapted to carry electric lamps, but the time has come to relegate them to the scrap pile. Heavy to start, and difficult to stop, locomotives absorb immense inertia, and therefore retard motion when the electrical engineer requires acceleration, and maintain speed when he requires retardation. They also require heavier rails and larger sleepers throughout the whole length of the road than would be necessary were the multiple-unit system adopted, and we know now, authoritatively, how they produce excessive vibration.

But the multiple-unit cars require some modification for long-range spring-buffers, to gain full mechanical acceleration. The end-doors, with their platforms, should be abolished; thus giving the full range required by the buffers. Three doors on each side could then be used instead of two end ones, as now, on London "Tube" railways; thus allowing for some acceleration in the movement of the passengers: while, as the cars, with their electric brakes, would be permanently coupled up, it would seem that with a two-minute service the brakesmen could be reduced in numbers, and better employed on the platforms of the stations than on the trains.

Mr. Swinburne also said that the long steam railways were not yet ready for electrification, and that electrical engineers were certainly not ready, at present, to do it. Considering the cost of generating and distributing energy for long distances over which infrequent trains would run, and many of them slowly, it does not appear that electricity will ever supersede steam, directly applied, for such service. The locomotive is a fairly efficient steam engine, and unless water-power is available near such roads, it is likely to retain its present supremacy. That, however, does not prevent electrical trains being run on long

railways, for there appears no reason why high-speed trains, composed of one or two saloon carriages with electrical motors and charged accumulators always ready, should not be available at the principal stations as "specials," for which a high price can be obtained, and if those are successful, it will be but a step to daily limited express trains of the same character. Mr. Sinclair Fairfax.

Mr. Wood. Mr. REGINALD WOOD (*communicated*): I have read this paper with the very greatest interest. The constant-current series system is a perfect system: under perfect conditions. General traffic conditions must always fall far short of perfection. A railway system may be compared with an estuary, a small stream of energy flowing into it to overcome bearing and air resistance with a, maybe large, ebb and flow of gravitational and kinetic energy. Kinetic power is a term worthy of note. The electric system must have storage capacity for kinetic energy and power.

The arrangement mentioned as a variable speed-gear was described by me many years ago (1894) under its more general purpose as a means of reconciling difference of pressure between supplier and user. In this arrangement the whole of the energy used must suffer conversion. When the pressure of user and supplier is sometimes the same, for instance when the locomotive can at full speed take full line pressure, as in tramway supply, the two extra machines for controlling the supply to the locomotive offer advantages which must have escaped the notice of the authors, since they condemn the machines as "clumsy and inefficient." The machines must cost something, of course, but they only convert one-sixth of the accelerating and return kinetic energy, and they allow perfect control, and return of kinetic energy. The series parallel control wastes energy not only in the resistance, but also in the feeders, because the full current is supplied during acceleration when the power required is small. The use of two extra machines for controlling the locomotive allows a very considerable saving in the cost of transmission, because the current supplied by the line is not constant, although the locomotive current may be. The current supplied by the line is proportional to the power demanded by the locomotive; that is to say, the useful energy required by the locomotive is supplied by the line at full line pressure, and the only wasted energy which is supplied is the conversion loss on the small amount converted. There are several suggestions in the paper for making control more elastic, but they all amount to either more or larger train motors. Nothing has been advanced in the paper which, in my opinion, justifies the condemnation quoted above.

The use of the two extra machines enables one to realise under all practical difficulties the perfection which the series system could admittedly realise under ideal conditions only, namely, 100 per cent. load-factor on generators and on insulation. In addition, the parallel system is the most suitable to meet general and changeable conditions. In fact, the two extra machines enable us to do exactly what we want to do. The paper serves to show how vast is the subject. There are many separate points which could take a paper each.

Messrs. Swinburne and Cooper.

Messrs. SWINBURNE and COOPER (*in reply*): From the discussion it appears that the object of our paper has to some extent been misunderstood. It was not our object to advocate a constant-current system to the exclusion of other systems already in use, but rather to bring forward this system for consideration. In a paper of this kind it is impossible to go into matters of detail, and we did not feel it necessary to do so, because we are dealing with systems which are not in use, and the first thing to be done in such a case is to consider the possible advantages. If it is found that the advantages are worth considering, then we may go into matters of detail and see if a system can be worked out. We do not, however, wish to underestimate the difficulties, or to infer that they do not exist. But, on the other hand, nothing is gained by taking difficulties too seriously, for they can generally be overcome if it is really necessary that they should be overcome. The history of our industry is full of cases in which difficulties have been solved when it has really been found necessary to do so, and of systems which have been discarded but finally found to be of great value.

A great deal of the criticism that has been made amounts to saying that a series constant-current system will not work on railways because it has been found to be unsatisfactory on tramways. That is the attitude taken up by Mr. Dow. But it must be remembered that such attempts took place some time ago, that the sections were very short and connected by switches which were worked by the car itself. Since that time there has been a great advance in the design of constant-current generators. M. Thury has put down a number of installations on this system with generators up to about 350 k.w. at about 150 amperes. There seems to be no difficulty in working these stations, and the switch gear is very simple compared with that which generally appears in high-tension stations. On railways the sections would no longer be short: they might be any convenient length, and the switches would not be worked by the train but from signal-boxes, and would be simpler. At starting, the motors would not, of course, be given the full current. because this would mean that the acceleration is varied from zero to its full value almost instantaneously, which would cause discomfort to the passengers. It is a mistake on the part of Mr. Geipel to say that constant acceleration is uncomfortable; it is reaching the constant value that is unpleasant. Discomfort is felt in starting a high-power motor car because the acceleration is varying the whole time up to constant speed (zero acceleration), there being generally no period of constant acceleration. The same thing applies to braking, though not to the same extent.

With regard to generation, extension of a series system is not so simple as in the case of parallel, because it would be inconvenient to go beyond a certain pressure, and therefore a single generating station would not be able to supply the same length of line if the traffic were heavy. This is no doubt a disadvantage. But the generators cannot be compared with arc lighters, for these were run at constant speed and the load was quite different from a motor load. That two conductors are required along the track instead of one is of course a disadvantage, but

Messrs Swinburne and Cooper.

the arrangements for switching are simpler, and high-tension direct-current is likely to give less trouble than alternating in transmission. Transformation should not be required except for lighting purposes, and can, of course, be effected by a motor generator.

Referring to the general problem of electric traction, we do not wish to suggest that main lines cannot be worked electrically, but we do wish to emphasise the great difference between this problem and that of urban lines. No doubt, as pointed out by Mr. Langdon, certain economies may result, for example in the supply of water, in repairs, and in reduction of weight; but the capacity of the line cannot be much increased by changing the motive power, because different classes of traffic have to be dealt with, and the speed of many of the trains cannot be raised to any great extent on the existing permanent way, even if it were not prohibitive from the point of view of cost. Therefore the question of efficiency is more important on main than on suburban lines. In the case of steam traction, the power is supplied direct; but in electrical methods there are transformations, and the total plant capacity is much more than that of the locomotives, for there is first the steam plant, then the generators, and finally the locomotives, with possibly transforming plant as well. The capital cost is therefore necessarily high, compared with steam locomotives, and although there is the advantage of a more or less constant load, this advantage may be lost to a large extent through these transformations, particularly if the system is not efficient. Thus simplicity in distribution is more important on main than on urban lines.

In referring to Table VI. it is well to remember that the figures there given are mean results for all classes of traffic. In the case of passenger trains the cost of locomotive power is less, whereas that for goods trains is higher, and for mineral trains still more. It follows, therefore, that economy is more likely to be obtained by applying electrical methods to goods and mineral trains than to passenger trains.

On urban lines the question of torque is, of course, most important. The steam locomotive can be made to give a high torque if not for high speed, but the unevenness of the torque prevents full advantage being taken of it. We do not wish to infer, however, as Mr. Geipel seems to think, that the steam locomotive can compete against the electric motor. The latter, besides having great torque, acts in a way, as pointed out by Professor Carus-Wilson, as a change-speed gear, in varying the torque per ampere. But as long as the amperes have to exist at the full pressure with only a small back E.M.F., the result cannot be considered as very satisfactory. The desired effect is, of course, obtained in the Leonard system, but the weight would be heavy and the efficiency low in transforming from alternating to direct, though not in dealing simply with direct current, which is apparently the particular case considered by Mr. McMahon. But it is preferable that the whole of a line should be worked on the same system. We do not suggest three systems, as Mr. Geipel seems to think, although there may be some difficulties at sidings; these, however, have probably been exaggerated.

Mr. Crawley remarked that a power-factor of 0·7 in the return of

Messrs Swinburne and Cooper.

energy was not a serious objection to the three-phase system, because the wattless current requires practically no energy. It is not the additional current, however, that makes the return of energy useless, but the effect which the low power-factor has upon the generators and other motors.

Mr. McMahon has criticised the figures in Table I. rather in the light of his experience on the City and South London Railway. The calculations were based to some extent upon the results obtained on the Liverpool Overhead Railway, as these show how much the power is liable to be increased by a high acceleration. Of course the generating station may have to be larger, but in practice the power required would not increase so much as is shown by the theoretical diagrams in the paper because a constant acceleration would not be maintained up to full speed. No doubt the load for each train would be on the station for only a short time, but as the number of trains on an urban line is large, the total load on the station would be fairly constant. High acceleration may mean increased total cost, but this may be more than compensated by an increased capacity of the line. It is difficult to see how a line like the City and South London Railway will be able to compete successfully in the future with a well-managed electric tramway running parallel to it unless high acceleration and high average speed is adopted. Passengers must be offered some inducement to go out of their way to an underground railway.

The use of buffers, mentioned by Mr. Fairfax, would assist only during a very short part of the time of acceleration, and when the speed is very low, so that any saving effected by such a method would be very small.

Mr. Digby does not think that uniformity of locomotives is important. Most people, however, will agree that it is very desirable about large towns, where locomotives of different lines frequently run on the same metals, as for instance at Aldersgate Street.

It is no doubt desirable to avoid complication of conductors at points and crossings, but we fear that the arrangement suggested by Mr. Holroyd-Smith would be easily carried away.

The President.

The PRESIDENT: There are one or two points which have transpired during the discussion on which I should like to make an observation. It has been remarked that uniformity of gauge and pressure is of very great importance. Unquestionably such is the case, more so with electrically driven vehicles than with steam driven vehicles. With railway traffic conducted by the steam locomotive, each company has its own stock for the purpose. The vehicles of one company pass over the lines of other companies, but they are almost invariably drawn by the engine belonging to the company possessing the line. When the time comes to deal with the traffic electrically there is no question but what each or several of the vehicles will be provided with their own motors, and therefore there is, in considering this question, the greater necessity for uniformity than is the case with steam railways. Standardising then is of importance.

A question has been raised with respect to conductors. It has appeared to me throughout this question of electric traction for rail-

The President.

ways that the means of conveying the current to the vehicles and its collection is the fundamental question; and although I do not wish at all to throw cold water upon the overhead system, yet I should like to recommend that the surface system should receive as much attention on the part of engineers as the overhead means of conveying the current. There can be no question but what two conductors might be established on the sides of the lines of railways readily enough, but in that case it means that the collectors must be established at a sufficient distance apart on the vehicle or throughout the train as shall provide for the break that must take place where lines of railway intersect one another.

I am quite sure that you will readily accord the authors a very hearty vote of thanks for the excellent and interesting paper they have given us.

[The vote was carried by acclamation.]

We have now to take into consideration the model General Conditions which have been, after much consideration, prepared by a Committee appointed by the Council to deal with the subject, the object being, of course, to get together such general conditions as might be acceptable to the profession. It is perhaps needless to say the Council desire to obtain the views of all members who are competent to give advice with respect to the wording of the several sections.

A Form of MODEL GENERAL CONDITIONS[1] recommended for use in connection with contracts for Plants, Mains, and Apparatus for Electricity Works, prepared by a Committee appointed by the Council, and ultimately to be presented to the Council for adoption as the Form recommended by the Institution, was now submitted to the meeting.

The discussion on these General Conditions was opened by the Reporter to the Committee, Mr. Robert Hammond, and was continued by General Webber, Mr. J. S. Raworth, Mr. J. A. Jeckell, and Mr. G. H. Nisbett.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members:

Harold Dowson. | Jack Hissink.
Frank A. Newington.

Associate Members:

Wm. Jas. Woodward Bullock.
Harry Crowther Caldwell.
Wm. John Head.
Ed. Massey Hollingsworth.
Wm. S. J. A. Jones.
Ernest Marples.
Geo. H. P. Morgan.
Paul Somerville Thompson.
Albert Richard Tudman.

[1] The General Conditions not being in their final form, it has been decided not to publish them in the Journal at this stage. The notes of the discussion have been laid before the Committee for consideration.

Associates:

Geo. Herbert Carter.
Anthony Hedley Chisholm.
Arthur Rainsford Craddock.
William Fletcher.
Arthur Wm. Greville.
George Hardwick Hardwick.
Joseph Josephs.
Wm. Lang.
Arthur More Simpson.
Karl Otto Swan.

Student:

Wm. Jas. Procter.

The Three Hundred and Seventy-Eighth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, May 1, 1902—Mr. WILLIAM E. LANGDON, President, in the Chair.

The Minutes of the Ordinary General Meeting held on April 24, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that their names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Frederick Augustus Cortez-Leigh. | Edward Ernest Hoadley.
Jonathan Edward Hodgkin.

From the class of Associates to that of Members—

Charles Vickery Drysdale. | Alfred Schwartz.

From the class of Associates to that of Associate Members—

Herbert Bryan Poynder.

From the class of Students to that of Associates—

Llewellyn Rolls Lester.

Messrs. J. J. C. Bacon and S. Joyce were appointed scrutineers of the Ballot for the election of new members.

Donations to the Building Fund were announced as having been received since the last meeting from Mr. A. A. Crawford, and to the Benevolent Fund from Mr. R. J. Wallace Jones, to whom the thanks of the Meeting were duly accorded.

The PRESIDENT: I have to announce that the Conversazione is appointed to take place on July 1st at the Natural History Museum, on which occasion opportunity will be taken for meeting some of the members of the Municipal and Electrical Association, and also to receive the foreign delegates to the Tramways and Light Railways Congress, who will be in England at the time.

I have also to announce that the Institution is convening a Conference of representatives of the Electric Light and Traction Industry with reference to the Factory and Workshops Act. This meeting is appointed to take place at 3.30 p.m. on Monday, May 12th,

at the Society of Arts. The object is to elicit expressions from the engineers or chairmen, or those who may represent them, of companies and Corporation Committees operating electricity and generating stations with reference to the effect of this Act in respect of generating or transforming works, and also to ascertain whether they are desirous that the Institution should take any action in the matter. The Institution, I need not say, desires to fulfil any duty which may be called for by the meeting.

I have now much pleasure in calling upon Mr. Brown for his paper on automatic relays.

AUTOMATIC RELAY TRANSLATION FOR LONG SUBMARINE CABLES.

By S. G. BROWN, Associate Member.

The system of relay working for long submarine telegraph cables here described must not be looked upon as being in an experimental stage. It is in everyday use on some of the lines of the largest Cable companies, notably of those of the Eastern Telegraph Company, their station at Gibraltar having been the first to be fitted up for automatically translating cable messages between Porthcurnow in England and Alexandria in Egypt.

The usual methods employed on cables at the present time is to receive signals on a strip of paper, written by a siphon recorder, as a dotted ink line. The message at an intermediate station is then punched by hand on another strip of paper, which strip is passed through an automatic transmitter for retransmission over the next line. Or, if the speed of signalling and the conditions of the circuit will allow of it, the message is read off the siphon recorder strip by the clerk, direct, as it flows from the instrument, and sent on by a hand-key, signal by signal. This latter system is termed "Human Translation," the speed being necessarily limited by the possible rate of hand transmission, and it is slow, laborious, and permissible at only one station. A cable relay is, therefore, valuable in that it replaces the clerk in all these operations, receiving and sending on the traffic automatically, whatever may be the speed of transmission. I believe the provision of a Submarine Cable relay has been one of the problems, to the solution of which the attention of telegraph engineers has been turned for some

years. The requirements in such an instrument are great sensitiveness, combined with the capability of being worked at a high speed by the feeble forces available at the receiving end of a long cable, and the absolute assurance of perfect contact. With the exceedingly feeble current obtainable at the end of cables, when operated at their present working speed on the siphon recorder, it is useless to bring two pieces of metal into "butt" contact with the view of closing the circuit of a battery, so as to work, say, a Post Office relay, since the resistance of such a contact may be normally many thousands of ohms, whilst, if the local battery is increased so as to break down this resistance, the contact on passing a current coheres or sticks together and prevents the cable current from opening the circuit. This disturbing force, although a great drawback in sensitive relays, has been effectually made use of for purposes of Wireless Telegraphy.

Varley, in his patent No. 3,456 of 1862, proposes to get over the difficulty of the relay contact sticking after the passage of the current by revolving the contact pieces, but I have found by actual experiment that such a movement actually increases the trouble of making contact, so that, on the whole, the remedy is as bad as the disease. I have found, however, that with such a form of relay, the resistance of the contact could be reduced by the use of a suitable short-circuiting condenser.

About the early part of the year 1899, I discovered that good electrical contact could be made and maintained by keeping the end of the relay tongue pressed upon the surface of a divided plate, and that frictional resistance to side motion of the tongue could be reduced and almost eliminated by moving the plate under the tongue, or what amounts to the same thing, by moving the tongue over the surface of the plate, the movement in each case being maintained in the direction of the length of the tongue. To obtain the best effect and greatest sensitiveness, the relay tongue is arranged in practice to move across the surface of a rotary drum, the drum is divided into insulated sections, and the sections joined to Post Office or similar relays. This relay is called the "Drum Cable Relay."

In Fig. 1, *a* is a recorder coil suspended in the field of a permanent magnet *M*; *f* is a light suspended frame

to carry the relay tongue *p*; the frame is joined to the suspended coil *a* by two silk or quartz fibres. The pointer *p* is a fine siphon glass tube carrying through its bore a phosphorbronze wire. This wire is soldered to an iridium tip, which tip is shellacked to the extreme end of the siphon tube. The iridium tip bears lightly upon the surface of the drum *D*, which is kept revolving at about 150 revolutions per minute. The drum *D* is made in three parts: the two outer ones, *d′ d″*, constitute the "dot"-

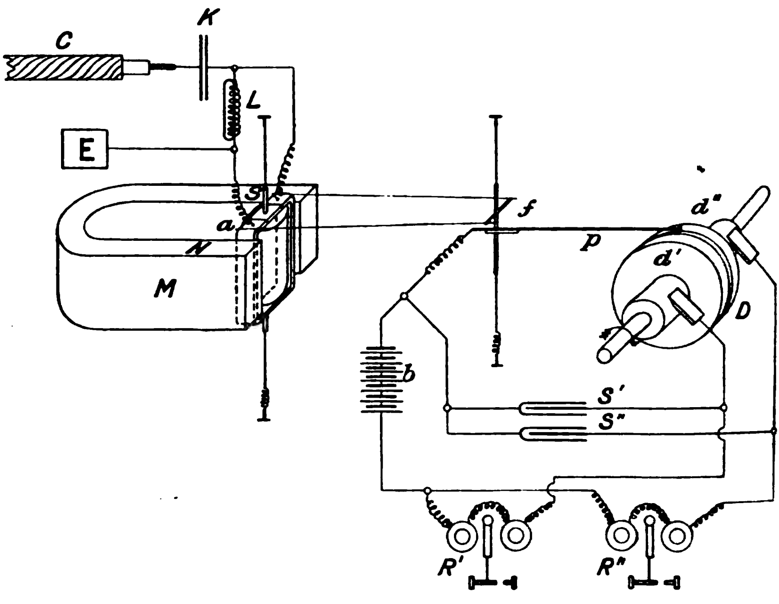


FIG. 1. (See also Plate 1, pp. 1074, 1075.)

and "dash"-marking surfaces, and the middle one, upon and in the centre of which the pointer normally rests when no signal or current passes, is insulated. When the tongue is deflected by the movement of the coil to form say a dot, a circuit is made through the battery *b*, the tongue *p*, and the Post Office relay *R′*. A movement of the tongue in the opposite direction would close the circuit of the Post Office relay *R″*.

The relay depends for its efficiency upon the reduction of frictional resistance to the lateral movements of the tongue, and it is easy to prove that this effect is due to the

tangential motion of the surface, for if the drum is stopped when signals are being received, the tongue also comes at once to rest, since the currents leaving the cable are of insufficient strength to overcome the statical friction between tongue and surface. This principle is somewhat ignored, I am afraid, in most treatises on friction; might there not be a parallelogram of friction corresponding to that which we use in dealing with Force and Motion?

S′ S″ are condensers of 2 microfarads capacity each, used to short-circuit the sliding contact between the tongue *p* and the drum *d*. Without them, good electrical contact can only be maintained when the surfaces of the drum and the tongue are very much cleaner than they can possibly be kept in practice. Why these condensers do improve the contact, making the contact practically perfect, I am not prepared to say. One eminent electrician maintains that this proves the existence of a vibratory contact. We all know why a condenser improves a vibratory contact, but I hardly think this touches the root of the matter, because I find that when the surface of the drum is exceptionally smooth the value of the condenser is usually more pronounced.

K is the receiving condenser. This condenser is placed in the circuit to act as a curb to the signals and to block out earth currents. The current from the cable *c* passes through this condenser before flowing round the suspended coil *a* to the earth plate *E*. The placing of the condenser *K* in the circuit introduces a difficulty due to its becoming charged under a succession of signals of the same polarity, producing what is termed "Variable Zero." This variability of zero which, unless special means are provided for its elimination, always occurs in cable signals when receiving condensers are employed, is of little or no importance if the siphon recorder is used as the receiving instrument, but is fatal to the working of a relay of any form.

Whilst experimenting with Mr. A. L. Dearlove at Porthcurnow on the Gibraltar-Porthcurnow cable of the Eastern Telegraph Company, the variability was got rid of by placing a high resistance shunt across the receiving and transmitting condensers, but this method was not found quite practical owing to the fact that earth-currents were

not entirely excluded by the shunted condensers. The consequence was that the earth-current temporarily upset the adjustment of the relay, and this mode of working was objected to by the Company. For this reason I devised another method, which in practice has been found entirely satisfactory. I shall explain it here as briefly as possible.

"Variable Zero" may be got rid of by means of "Local Correction," that is to say, a current from a local battery and the relay R' R'' is sent through a circuit having considerable retardation made up of a condenser placed between two high resistances, condenser and resistances being capable of minute adjustment. The relays R' R'' produce the same order or combination of signals as that charging up the condenser K. As the current from the cable, due to this choking action of the condenser, dies away, so at exactly the same rate does the current from the local correction circuit increase. The correction current flows through a separate winding on the suspended coil *a* in the same direction as the signals, so as to compensate for the loss of current from the cable, thus eliminating "Variable Zero" disturbances entirely from the working of the relay.

L is a magnetic or inductive shunt of 30 ohms resistance, joined across the terminals of the suspended coil *a*. The shunt can be adjusted to suit cables of from 1 to 10 K.R.; the largest size at present used has a very high self-induction. I am not at present prepared to say what the value is. It is secured by the use of many thousands of turns of copper wire, and a heavy closed magnetic circuit. The mechanical arrangement of this shunt is on the lines of the well-known "Mordey" transformer.

Roughly speaking, to get high inductance to deal with the slow changes of current from a cable, we must have weight. Our largest shunt turns the balance at something like 3 cwt. When operated by the cable currents from the end of a line, the iron of the shunt must be magnetised only in its initial stage, the molecules being magnetically strained well within their elastic limit. In support of this statement, I shall refer you to Professor Ewing's book on "Magnetic Induction in Iron and other Metals," chap. vi., from which the following is more or less a quotation.

Lord Rayleigh in testing magnetometrically a bar of

iron, one end of the iron being very near the magnetometer, and with a compensating coil adjusted to balance the magnetism, which a feeble magnetising current induced in the bar, found that the compensation remained perfect if the magnetic force fell below 0·00004 C.G.S. Within this range of force there is no retentiveness. The magnetising process begins like the straining of a solid body with an elastic stage, within which there is no permanent set. Some electricians have thought that there must be a drawback to the use of iron in these shunts, especially as the iron forms a closed circuit. They have suggested air as being a more perfect material, but I think the above well meets their objection. The permeability of the iron of these inductive shunts when used for cable work is probably somewhere about 150 as against the 1,200, or thereabouts, when used as transformers for alternating-current lighting work, the permeability of air being 1.

Magnetic shunts have been designed, so that the molecules of iron may be shaken up by an alternating-current excitation. This alternating-current circuit is disposed so that there shall be no interaction between it and the shunt-winding. The permeability of the iron may thus be greatly increased. The method has been tried with satisfactory results. These magnetic shunts are of very great value in cable work, for they steady and curb the action of the relay coil, and without them relay working would be well nigh impossible. Their action on a siphon recorder is no less marked : using a "plain" automatic or hand-key as sender, they produce curbed signals, and this with an increase of speed.

The Drum Cable Relay apparatus, so far as I have described it, is all that is necessary for simple translation on short cables, a hand-key being used at the first station, the relays *R′ R″* being connected to work two sounders, which sounders are joined up with a battery, in the same way as a hand-key, to transmit the messages over the second line ; but in what follows I shall assume that at the originating station an "automatic transmitter" is employed.

Although scarcely necessary, it may be well here to call attention to the fact that when a cable is worked at its highest practicable speed, many of the originating impulses are obliterated from the received signals whenever successive

impulses of the same polarity or sign occur. It is therefore evident that if the impulses sent by the relay apparatus into the second cable are to be identical in character with those sent into the first, it is necessary to reproduce the missing "beats." The instrument used for this purpose is called an "interpolator." Its action resembles that of the automatic transmitter at the originating station, with this difference, that the movements of its transmitting levers, instead of

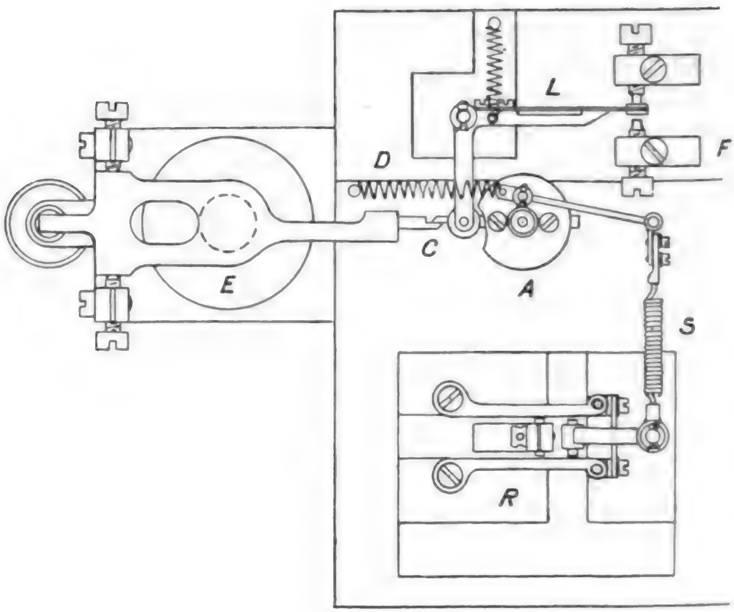


FIG. 2. (See also Plate 2, pp. 1074, 1075.)

being governed by the perforations in the punched tape or strip, are governed by the motions of the relay tongue. The interpolator sends into the second cable impulses similar to those entering the first cable, and these may be either "curbed" or "plain" as required. To use this instrument to the best advantage, it is necessary that it should run in approximate synchronism with the automatic transmitter, and that the speed of the last-named instrument should be nearly uniform.

The interpolator consists of two sets of signalling levers, similar to each other but mechanically distinct. One set

sends on the "dot" signals and the other the "dashes." Fig. 2 shows the mechanism of one-half of the interpolator, which acts as an automatic transmitter, forwarding the "dot" signals received by the drum relay from the first into the second cable. The electromagnet *E* is worked from the relay *R'* of Fig. 1. The other set of mechanism, or "dash" side, not shown, is worked from the relay *R''*. When the electromagnet *E* is energised it pulls down its armature, removing the catch *C* from holding the clutch-sleeve *A*, allowing it to revolve. The clutch-sleeve as it revolves moves the lever *L* so as to make contact with the lower contact point *F*, this putting battery to line. *S* is a spring-lever worked from a crank-pin on top of the clutch-sleeve; the crank-pin revolving, rocks the lever and operates the reverser *R* to which the battery is connected, and this, at stated times in the revolution, reverses the battery, which acts as a curb to the first battery current, or cutting off the battery and putting the line to earth, to act as "plain" automatic as the case may be. By moving the reverser *R*, relatively to the crank-pin, a bias may be given the spring of the lever *S*. Such a motion will allow of the duration of the curb or earthing period being adjusted. *D* is a spiral spring to help the clutch-sleeve to ride over its lifting rollers. The clutch mechanism is driven by a small governed electro-motor. The clutch is more particularly shown in Fig. 3.

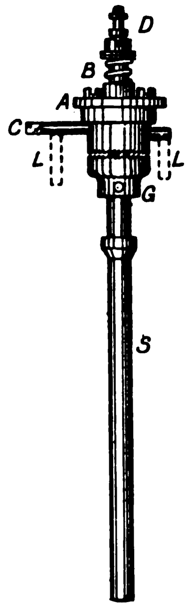


FIG. 3.

S is a rotating spindle to which the collar *G* is fixed. The clutch-sleeve, loose on the spindle, carries at its end the cam plate *A*, is provided at its lower end with teeth, which are adjusted to gear with similar teeth on the collar. A spring *B* tends to force the clutch-sleeve into engagement with the collar. The sleeve is provided with pins or projections, one of which, *C*, engages with the arresting device, and these ride upon fixed lifting rollers *L L* (which are shown dotted) when the sleeve is at rest, and thereby raises it out of engagement with the rotary spindle. When the arresting device is removed by the

magnet *E*, the clutch-sleeve is pulled off the rollers *L L* by a spring pulling at the crank-pin *D*, and thus thrown into gear with the spindle, operating the transmitting levers as previously described.

When an *h* is received from a long cable on the drum of the relay, the tongue remains in contact with the dot side throughout the four beats of the letter, simply producing one long contact on the "dot" Post Office relay. This long signal is split up by the interpolator and transmitted as four dots.

In place of the interpolator, an "automatic perforator" (see Plate 3, at end) may be employed. The automatic perforator is constructed very much like the interpolator, with this difference, that in place of two there are three clutches adapted to operate punches, by means of cams, for per-

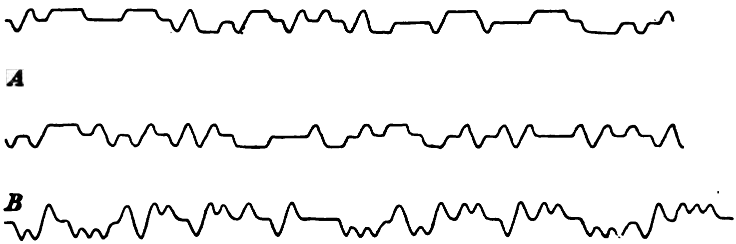


FIG. 4.

forating the signals on a paper tape, such as is employed when using the automatic transmitter. To prevent waste of paper, a stopping device is brought into action after the machine has fed out, say five inches of blank strip, this after the last signal has been received. The perforator reproduces on punched tape a facsimile of the message on the punched tape used at the originating station, and the copy is immediately available for sending on by the usual automatic transmitter. By the use of this auto-perforator it is possible for a single short cable to feed two long ones, or *vice versâ*, with a minimum of delay.

In order that slight failures in the relay apparatus may be instantly seen, it is necessary to have two local registers at the transmitting station, one showing the drum and tongue contacts, the other the signals actually sent into the second cable. The register for showing the drum and tongue contacts of the cable relay has been found to be most valuable

and efficient, and automatic translation cannot very well be maintained without it, for it gives a record of what takes place in the most delicate part of the apparatus undisguised by defects of the Post Office relays, or the defects and corrective effects of the interpolator.

Such a record is seen in Slip *A* of Fig. 4. These signals were recorded by a direct writer, worked straight off the Drum Cable relay. It shows the quality of the contact, and gives an outline of the signals as they arrange themselves on the drum when everything is in correct adjustment. By observing such a record, the relay may be kept in adjustment and faults in transmission easily detected.

Slip *A* is a record of signals received from a cable relay direct at 140 letters per minute over a duplexed cable of 3·2 K.R. under actual traffic conditions. It will be ob-

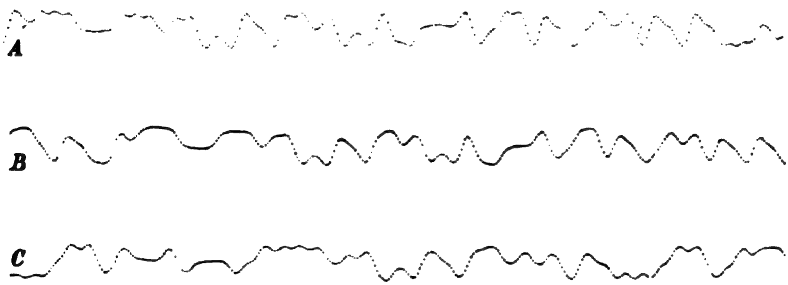


FIG. 5.

served that there are no "beats" in the signals when the same follow each other on the same side of the line, the tongue of the relay having held over in these cases without breaking contact.

On the other hand, Slip *B* shows signals recorded by a direct writer worked off local circuit with the interpolator; here we have all the signals clearly recorded. Such a record was received from a relay over a cable of 2·8 K.R., simplex working at 210 letters per minute under actual traffic conditions.

In Fig. 5, Slips *A* and *B* show records of signals received on the Drum Cable relay apparatus, worked from a duplexed cable of 2·8 K.R. at 150 letters per minute; the sending battery was 60 volts. The signals were translated by the relay apparatus through an artificial line of 3·5 K.R., the signals being written by a siphon recorder.

Slip *A* shows signals as received on the siphon recorder when an automatic transmitter was used at the originating station; the message was sent on from the relay by a "curb" interpolator. Slip *B* shows signals as received when a couple of sounders were joined up like a hand-key to be worked by the relay in place of the interpolator. Slip *C* shows signals transmitted under similar conditions as Slip *B*, but a hand-key was used in place of the automatic transmitter at the originating station.

Having finished the description of the Cable Relay

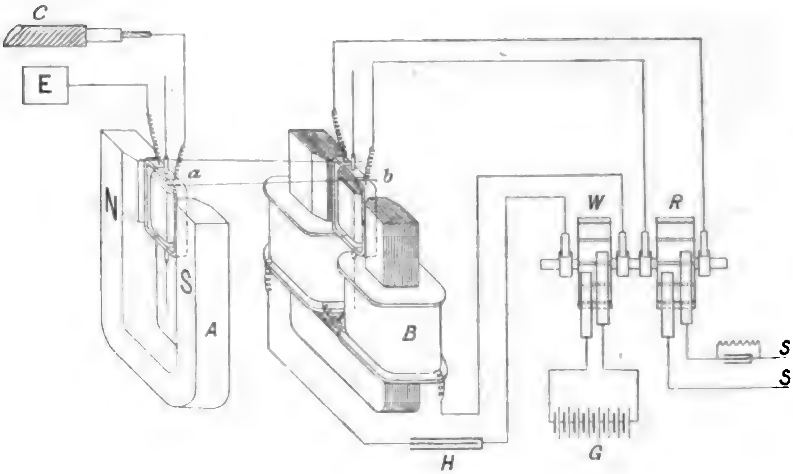


FIG. 6. (See Plate 4, pp. 1074, 1075.

Translation apparatus, I wish now to describe briefly the "Magnifying Relay," a relay that was the forerunner of the "Drum Cable Relay." I invented the "Magnifying Relay" in the year 1898. It is not, at present, employed on any of the cables, but I know no reason why it should not be of great use to the Cable Companies in the future.

As shown in Fig. 6, the instrument consists of a permanent magnet, or direct-current electromagnet *A*, and of an alternating electromagnet *B*. In the field of the magnet *A* is suspended a "recorder" coil *a*, say of about 500 ohms resistance; in the field of the alternating-current magnet *B* is suspended another and similar "recorder" coil *b*.

The suspended coils *a* and *b* are coupled together by silk fibres, as is shown in the drawing. The arrival current from the cable *C* flows through the coil *a* to the earth-plate *E*, causing the coil to move, and as the suspended coil *b* is joined to it by the fibres, *b* will follow the motion of *a*. *G* is an electric battery. *W* is a current reverser that turns the direct current from *G* into an alternating one. *H* is a condenser of suitable capacity, placed in the circuit so as to neutralise the self-induction and stop sparking at the current reverser *W*.

If *W* is revolved at a proper speed, the magnetic lines of force will be moving in and out of the iron of the magnet *B*, say at a periodicity of 100 ∿, threading through the suspended coil *b*, when it is at all moved out of its normal or neutral position, and inducing a voltage, proportional to the angle, or more correctly, perhaps, to the sine of the angle of deflection. By these means energy may be generated in the coil *b*, which may be hundreds of times greater than that employed to move the coil, this greater energy increasing and diminishing in exact proportion to the rise and fall of the controlling current. I should compare this action, if I may be allowed the licence, to a driver directing the energies of a horse by a pair of reins. *R* is a rectifier revolving on the same shaft as the current reverser, so as to turn the alternating current induced in the suspended coil *b* into a direct or unidirectional current in order that it may operate a "siphon recorder," "direct-writing recorder," or any other suitable instrument, as the case may be, the instrument being placed in circuit with the lead *S S*.

If the circuit of the coil *b*, that hangs in the alternating-current field, possesses only resistance, the induced current will produce no disturbance on the period of the coils, or on the sensitiveness of the suspension.

To explain this, in Fig. 7 I have drawn theoretical diagrams representing sine wave curves. *I* is the curve of magnetic induction, *A* the curve of induced volts, which is, as is well known, at right angles to the curve of magnetic induction, and *B* is the current curve, which flowing in a circuit of plain resistance would be exactly in phase with the induced volts. This being so, the amperes, as a whole, will produce no reaction on the alternating field *a I e*,

because, as is seen, the portion *a b c* is exactly equal to, opposed, and neutralised by, the portion *c d e*. But it is otherwise, if there is capacity, because then the amperes will be accelerated, this acceleration being due to two E.M.F.'s impressed on the circuit, one due to the moving magnetic lines, and the other to the voltage stored up in the condenser, the portion *a b c* being less than that part of the curve *c d e*, the difference acting on the magnetism so as to cause the coil *b* to move out of the field. If there is inductance, the contrary action will take place,

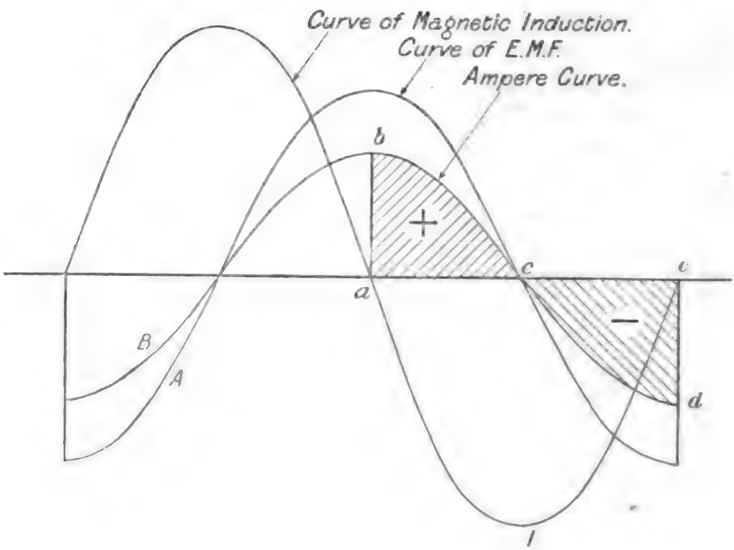


FIG. 7.

in which case, the part *a b c* being greater than the part *c d e*, the coil will then endeavour to remain in the field opposing the action to move it out.

Capacity has the same effect as slackening the control of the suspensions, increasing the period of the coils and making the instrument more sensitive, while induction stiffens up the coil reducing the period. This being so, a ready means for adjustment is provided for by plugging in induction or capacity, the control over the coils may be instantly increased or lowered, and this is so, whatever may have been the initial mechanical control, within reason.

I have arranged the instrument, on some occasions, to

work with only one suspended coil, combining the alternating and direct currents on one field-magnet, the current from the cable passing through a choking coil before flowing round the suspended coil. The choking coil stops the induced alternating current from flowing into the cable, while the current from the cable is blocked, say by a condenser, from flowing past the rectifier and wasting its energy in the local circuit. Such a single-coil instrument acts as well as a double-coil one, but I do not know if it possesses any special advantage except on the score of mechanical simplicity.

On trial with the magnifying relay over an artificial

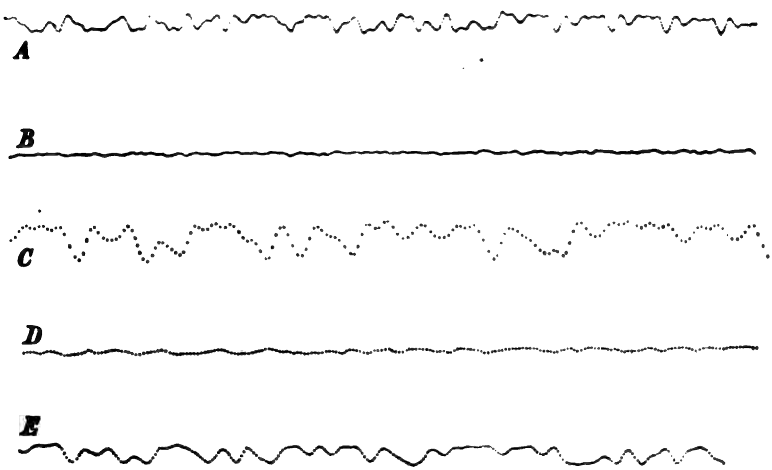


Fig. 8.

cable, I have obtained some rather interesting results. For instance, the Slip *A* in Fig. 8 shows signals written by a siphon recorder, worked by a "magnifying relay." The "magnifying relay" acts as a receiver at the end of an artificial line of 7,000 ohms resistance and 310 microfarads capacity. An automatic "curb" transmitter was used as sender, the speed being 150 letters per minute, the sending battery having a potential of only 3 volts. Slip *B* shows the signals received under identical conditions, but with the "magnifying relay" cut out of circuit, the siphon recorder acting as receiver direct. Again, the Slip *C* shows signals written by a siphon recorder worked off a "magnifying relay," while Slip *D* shows the signals

as received by the siphon recorder direct, the relay being cut out of circuit. The currents were transmitted by an automatic "curb" transmitter at 185 letters per minute, with sending battery of 50 volts, the K.R. of the line being 3·6.

Slip *E* shows signals received at a fairly high speed, the siphon recorder being worked off the induced currents of the "magnifying relay," as in slips *A* and *C*, the artificial line had a retardation of 3·6 K.R., the automatic "curb" transmitter was sending with a battery of 42 volts, the speed of signalling was at the rate of 280 letters per minute.

When signals at a moderate speed were being received on the particular magnifying relay used in these experiments, it was difficult to detect by the eye any motion whatever in either of the suspended coils when observed through a strong magnifying glass. Though small in amplitude, it is certain that the motion occurred from the fact that the currents induced thereby were sufficient to cause large and very visible movements in the signalling coil of the siphon recorder.

The "magnifying relay" seems to possess three main points of advantage for cable working:—

1. It may be used to work the siphon recorder with the signals of the same size, and at the same speed as at present, but with greatly reduced sending battery power.

2. It may be used to work the siphon recorder with the signals of the same size, the same definition, and the same sending battery as at present, but at a greater speed.

3. I believe it may be used to work over a cable under the same conditions as regards speed and battery power as at present, but the signals may be written by a "direct writing recorder" in place of the present "siphon recorder."

Now I should like to suggest a use for this instrument or part of the instrument for electrical engineers other than telegraph men. Referring again to Fig. 6, and considering only that part marked *B b*: If the winding round the magnet is supplied with an alternating current, say of sine wave form, we have seen that if induction or capacity is introduced in the circuit of *b*, the rectifier being dispensed with, the current flowing in the circuit will be put out of phase with the induced volts, and a mechanical

PLATE 1.—" Drum " Cable Relay (*see p.* 1061).

PLATE 2.—Interpolator (*sec p.* 1068).

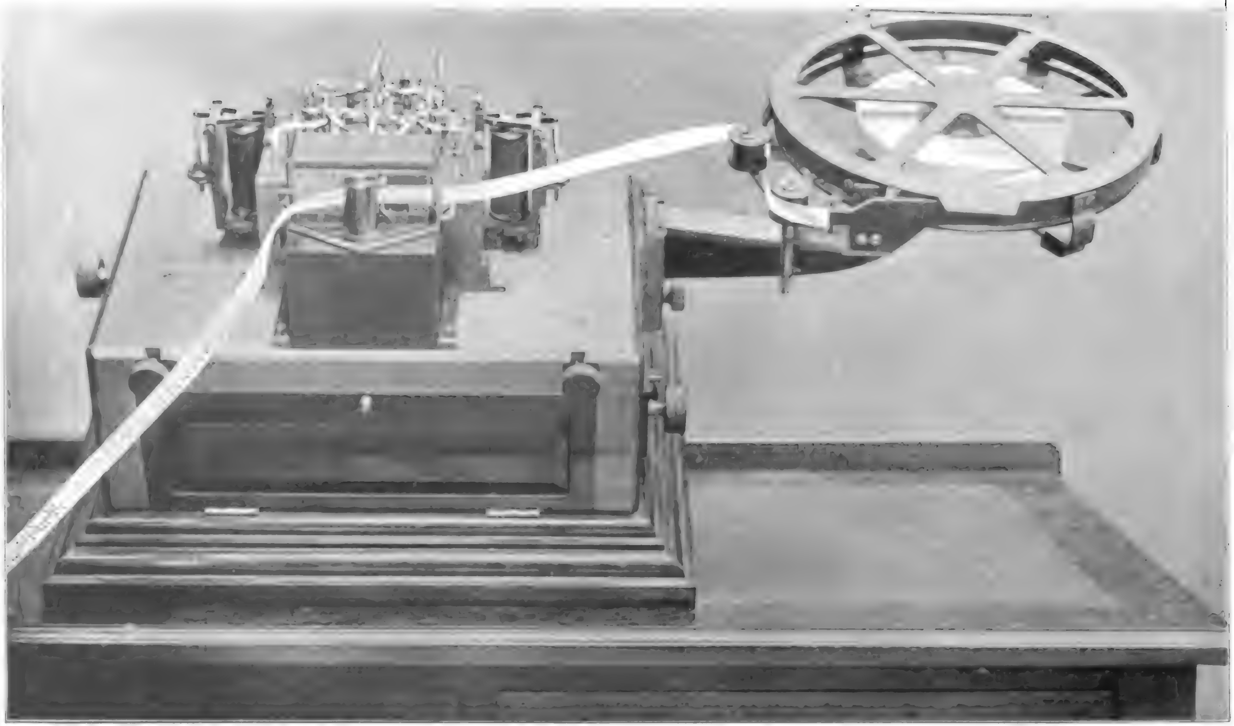


PLATE 3.—Automatic Perforator (*see p.* 1068).

PLATE 4.—Magnifying Relay (*see p.* 1070).

reaction takes place between the coil *b* and the magnet *B*, the coil tending to move one way for induction, and in the opposite way for capacity, *b* being supposed suspended in such a manner as to cut some of the moving magnetic lines, its motion being studied by means of a mirror reflecting a spot of light on to a scale.

A complex circuit could be tested and compared with a standard, the deflection showing the resultant capacity or induction; or, perhaps, the capacity, say of such a thing as a coherer, could be found out by this means. I believe that such a reaction galvanometer could be worked up to measure capacity and induction in the same way as an ordinary galvanometer measures resistance.

Messrs. H. A. Taylor and A. L. Dearlove, both of the firm of Messrs. Clarke, Forde, & Taylor, pointed out this line of investigation to me. They gave the convenience and necessary encouragement, and have done all in their power to help me in every possible way, and I wish to acknowledge my deep indebtedness to them.

The PRESIDENT: Mr. Brown appears to have overcome a very great difficulty, and I am sure everybody in this room will join with me in hearty congratulations to him. This is a matter which, I think, is of very great interest to Professor Ayrton, and I am sure you will be very glad to see him here again with us this evening. Therefore, if it will not be taxing him too greatly, I will ask him to commence the discussion. The President.

Professor AYRTON: Mr. President, in response to your invitation I rise to open the discussion on this most interesting paper which Mr. Brown has given us, a paper which takes us back to the old days of twenty years ago when telegraphic transmission was the only electric transmission of power that we had anything to do with. The problem of transforming the signals of a siphon recorder, the blurred signals which are received at the end, say, of a long Atlantic cable into ordinary Morse signals such as are used on land telegraphs, has occupied a great number of people at different periods, but as far as I am aware this is the only successful practical solution that has ever been reached. I am sure the congratulations of the Institution must be given to Mr. Brown for having so successfully overcome the most obvious difficulties. The difficulties are obvious, but the method of overcoming them not by any means so. The idea of restoring the waves that have disappeared, that have been blotted out, is extremely interesting and ingenious. Those who are familiar with submarine telegraphy will understand at once what the problem of turning the Slip A on page 1068 into Slip B means. If you refer to A, you will see certain waves followed by horizontal straight lines. Of course an Professor Ayrton.

Professor Ayrton.

expert cable signaller knows by experience that the straight line is not meant for a straight line; it is meant for a series of little ripples, and by experience he learns to interpret it. He learns to do exactly what an ordinary clever clerk does, who has had given to him some very bad handwriting. A person scrawls a line, and the clerk knows from his experience of the scrawl of that particular individual that that scrawl means "having" or "becoming" or "possessing," or something of that kind; he does that by using his brain. And what Mr. Brown had to do was to invent a machine which had that sort of discriminating brain, so that when it saw a scrawl it should know what it meant. Although it is a very difficult problem, it is a little easier than it would be to invent a machine to decipher handwriting, because there is one condition in connection with the telegraphic scrawl that does not exist in connection with the handwriting scrawl, and that is the time taken to make the scrawl. If the horizontal line in the telegraphic signal, the siphon-recorder slip, has a certain curve, then the intelligent person knows that that means a certain definite number of ripples; if it is longer, he knows it means more ripples; in fact, he knows that since the apparatus goes at a uniform speed the length of the line is really a measure of the number of ripples. That Mr. Brown was sufficiently acute to see. So he said to himself, if I only make an apparatus which introduces ripples at a given rate, I shall put in the right number of ripples that have been blurred out by sending the message through the long submarine cable; the cable possessing capacity and resistance. It is a very interesting idea. Of course it necessitates, as he himself pointed out, in the accomplishment of the method that the two instruments shall run at nearly uniform speed. That is a necessity, but it is not a very difficult condition to comply with. Mr. Brown did not, I fear, make quite clear why the interpolator has to go at a fairly constant speed, synchronously with the machine at the other end; it is because it has to throw in ripples at a given rate for the reasons I have given you.

Going to the beginning of the paper, the first relay which he described, the drum-cable relay, is again a very ingenious contrivance—getting over friction by causing one of the bodies to be in continuous motion relatively to the other. Of course, as he himself says, that is not a new idea—what is really new is utilising it. We have known for a very long time that if one body has to move over another and you want to get rid of the friction, if you joggle or rotate one of the bodies, that will enable the other to move much more easily over the second. I have myself found in certain cases where I had to deal with delicate mechanism, and where I wanted to get rid of friction—and I have no doubt other people have done the same thing—that if you keep the whole of the apparatus in very slight vibration it is quite sufficient to accomplish the object. For instance, if you take a loud-ticking watch, such as I happen to possess, and put it on the table, and leave it there permanently, then the apparatus will work more or less frictionless because of the slight trembling that is perpetually kept up in the table. You cannot see it, but the slight trembling produced by putting a loud-ticking watch on the table is sometimes sufficient to overcome the friction and to enable the mechanism to work.

I will now take the last part of his paper, which has a special interest for me because he has obtained a solution of a problem which Professor Perry and I, at any rate, tried some ten or twelve years ago to solve in a different way—I do not suppose it was as good a way—which we patented at the time. The object was to do what Mr. Brown has accomplished in doing. Supposing you receive these telegraphic messages, that is, you receive slight variations in current, and you want to magnify them, how can you do it? You have all sorts of variations, alterations made in the direction of current, alterations in the magnitude succeeding one another with considerable rapidity, and you want to get an enlarged image of it, how can you do it? The way in which we tried to do it was simply this. You take a little dynamo running at a uniform speed; you use the field-magnet coil as the receiving coil of your telegraph line—that is to say, you magnetise your field simply by the current received along the telegraph line, the submarine cable. The armature is then rotated by any convenient arrangement, an electric motor or a clock, or whatever it may be, at a uniform speed. Then, as you see, the E.M.F. of the armature and the current therefore produced through a fixed resistance will be an exact copy of the wave which has come along the telegraph line, and which is used to magnetise the field magnet. Of course it may be a very much enlarged wave, because you are giving energy to the arrangement by the work done in driving your dynamo. The difficulty, however, of that contrivance was this. We, perhaps unwisely, aimed at getting an extremely perfect magnified image of the receiving current; we wished that it should be an absolutely perfect image, that there should be no errors, no imperfections, no irregularities introduced into the waves, the ripples, by the introduction of our apparatus—that we should simply get a magnified image. That necessitated having no iron at all in the dynamo, either in the field or in the armature. Then we were led to the unhappy conclusion that if you have such an apparatus, before you can introduce energy by such a contrivance as I have mentioned it is necessary to run your dynamo at a speed greater than the speed of self-excitation, which of course is enormously great if all iron be absent. Indeed, we feared that that would mean such a high speed as to make the thing impracticable; but talking over the matter some two years ago with Mr. Brown, when I had the pleasure of first seeing this apparatus in the offices of Messrs. Clark, Forde, and Taylor, he told me that he thought iron could be introduced without blurring the signals too much, and then, of course, the speed of self-excitation would be a speed possible to obtain in practice. After what Mr. Brown told me two years ago it seems that it really would have been possible, and is possible, for anybody now—the patent has expired, so anybody is at liberty to use the contrivance—to obtain a magnified image of a current in all sorts of ways by that contrivance. I should like to hear Mr. Brown's opinion on the subject, because I am not sure whether it is possible with the arrangement I have described to obtain as good a record as he has got. Of course he is met with the difficulty which he points out at the bottom of page 1071, where he says, "If the circuit of the coil *b*, that hangs in the alternating-current field, possesses only

Professor Ayrton.

Professor Ayrton.

resistance, the induced current will produce no disturbance on the period of the coils or on the sensitiveness of the suspension." But that is an impossible supposition, for if the circuit possessed only resistance there could be no induced current at all. If the circuit of the coil *b*, that hangs in the alternating field, possesses only resistance, you may put it if you like that the induced current will produce no disturbance, but you ought to go on and say there will be no induced current at all. There is only an induced current when the coil *b* has self-induction. Imagine, for example, that the coil *b* were wound non-inductively so that it only had resistance. Then there could be no mutual induction between the electro-magnet *b* and the coil; therefore there could be no current induced in that coil. It is necessary, therefore, that the coil should have self-induction. Then comes the question, that being the case, can you with your self-induction and capacity, which he refers to afterwards—can you so balance the self-induction of the coil as to get a perfectly true representation of the current through the coil *a*. I am not quite clear that you can, because, of course, the current in the coil *a* is varying in all sorts of ways, at different rates, and we know that capacity only balances self-induction for a given frequency. Of course I do not mean to suggest for a moment that this is impracticable; far from it. It is an extremely ingenious idea, and it certainly gets over one of the difficulties we had, viz., that iron can be used, and therefore a suitable magnification obtained without the difficulty I mentioned, the great speed of rotation. But I should like to know from Mr. Brown whether it is a fact that this arrangement, with all sorts of speeds of signalling, all sorts of imposed waves, ripples, does or does not give a better magnified image than the high-speed dynamo with the small amount of iron in it.

I can only conclude by saying what I said at the beginning, that I think the warmest congratulations of the Institution are due to Mr. Brown for the really wonderful result that he has succeeded in achieving, a result that is already, and doubtless will continue to be, of the very highest importance to our submarine cable companies, which, at the present time, want all the assistance they can get in view of the advance of wireless telegraphy.

Mr. Gavey.

Mr. J. Gavey: I have not many remarks to make on this subject. A few of those I had in mind have been anticipated by Professor Ayrton. Certainly the whole of the design of this apparatus is marvellously perfect. What strikes the observer most forcibly, far more forcibly than any mere verbal description, is to observe a slip which, owing to the capacity of an artificial cable, shows straight lines instead of ripples, whereas the corresponding slip as it is converted by this apparatus reproduces with exact accuracy the original signals. I hope, sir, Mr. Brown will continue his illustration after the close of the meeting, so that members of the Institution who have not had an opportunity of seeing the instruments working, except at a distance, will go away with a much more vivid impression of the beauty of the discovery than from merely reading the paper or from even listening to the author's very lucid description. One point has struck me in connection with the subject, namely, that it is very

Mr. Gavey.

curious in some cases how, when one inventor starts on a particular line of investigation, it is found that others are working, perhaps not with the same object in view, but also in the same direction. Our ideas of telegraphy in the past have always consisted of this one fundamental principle, that you send a separate impulse or a separate signal for every separate movement that you want to effect at the distant end. Now, owing to the capacity of long submarine cables, a lot of separate impulses in the same direction are converted into one uniform impulse at the distant end. Mr. Brown set himself to work to split up the received impulses into the original number of separate ones. Now in two other directions somewhat similar results have been achieved. In wireless telegraphy, to which reference has been made, you have the make and break of an induction coil, which sends impulses some 20 or 30 times per second; in other words, you have impulses lasting perhaps one-twentieth or one-thirtieth of a second, but owing to the capacity and induction of the conductor used in Hertzian signalling, your vibrations or oscillations of 10 or 20 per second are converted into oscillations of, it may be, 100 or 200 millions per second, and the result is you get an emission of Hertzian waves. In another direction in practical telegraphy there is an inventor, Mr. Donald Murray, who has designed what I think is also a very beautiful apparatus for high-speed telegraphy of the typing character. He has brought over here an instrument (which I hope in the next session to have the pleasure of describing to the Institution) which will transmit messages at the rate of 120 words a minute in Roman type. He sends a current of a definite duration, and his instrument at the far end splits up that current into the number of separate impulses necessary to actuate the typing machine.

The President.

The PRESIDENT: We are very anxious to hear expressions of opinion from gentlemen who are associated with the operation of cables, and I would like to ask Mr. Judd if he will join in the discussion.

Mr. Judd.

Mr. W. JUDD: I did not come here at all prepared to discuss the matter, beyond saying that we have been largely interested and have begun to adopt this very remarkable instrument of Mr. Brown's. It is working on some of our cables, and we hope it will work on others by and by. It is very obvious to any one looking at the apparatus on the table that it is not altogether a thing you could put down and leave to work by itself; it is an instrument which has its difficulties, climatic and others. With so much delicate apparatus, in tropical climates it is very obvious there is a certain amount of difficulty in keeping everything in absolutely thorough working order. But it is undoubtedly a great advance upon all our previous experience.

Mr. Sullivan.

Mr. H. W. SULLIVAN: I have had no personal experience of Mr. Brown's most ingenious instrument, and I think remarks would be more interesting from those who have. I should like, however, to say, with regard to a remark made by the author, that I think he rather exaggerates the trouble of what he calls "butt" contacts for relays. I was making some experiments myself some months ago on a long cable, and I used contacts which I think he would call "butt" contacts, and

Mr. Sullivan.

did not have the trouble which he seems to have experienced, in fact, it did not exist at all. I would simply like to ask Mr. Brown the longest length of cable on which he is able to work his relay without the interpolator.

Mr. Wilkinson.

Mr. H. D. WILKINSON: I think the speakers up to the present time have somewhat missed the real achievement which the author has effected. They have spoken of the possibility of reproducing ripples where they had ceased to exist. Where those ripples became lost in the signals at the receiving end of a long cable, Mr. Brown had put them in again. But I might just say that that is not, in my opinion, the greatest achievement the author has effected. As a matter of fact signals without ripples are just as easy to read as those with them, in fact, I may let you into a secret; we like them better, we read them better. Mr. Brown's real achievement consists in having reduced the friction in the contacts of the relay, so that it is perfectly free to respond to such minute forces as arrive at the distant end of a long cable, and to carry the local currents across the contacts without sticking. You have in the signals received at the distant end of a submarine cable the most minute forces, only sufficient to turn a light mirror weighing a few grains, or a light coil; and what to do with such a current having such an infinitesimally small force, in order to make it the means of sending on a stronger current to the next cable, has been the problem before cable engineers for years up to the present time. The difficulties have been enormous, and no one up to the present has solved the difficulty, although many ingenious contrivances have been made. I could mention the names of some, but as I do not just now recollect the names of all who have worked in this field, and it might be misunderstood if I inadvertently overlooked some names, I will not mention any. At all events, I will say that in the opinion of all cable engineers and electricians, the system which Mr. Brown has devised for utilising these minute forces, through the medium of a rotating drum in which he practically annihilates friction, which has been the bugbear in all previous attempts to overcome the difficulty, thus reproducing the signals by means of a relay, constitutes a marvellous invention. There is another point I should like to allude to. When Mr. Brown arrived at that stage he was confronted with another difficulty as great as, if not greater than that, namely, the wandering zero. As he has described to us in the paper, when you use a condenser at the transmitting and receiving ends of a cable, which you are bound to do in order to get the speed out of the cable, you introduce a wandering away from zero It is not the absence of ripples that is the trouble, it is the wandering away from zero. You must all be aware that if a relay is to act with accuracy and certainty it must come back to zero before every signal, otherwise you would have no possible means of reproducing the signals. Mr. Brown got over this first of all by shunting the condensers on the receiving and transmitting ends of the line, but that was not found to be satisfactory and was objected to, he said, by the Company, and quite reasonably so, because it would introduce the disturbing effect of earth currents into the signals. He then set himself to work to devise other means, and he hit upon the solution of using the local

circuit, that is, the current which was produced externally by his relay, to send back into the receiving instrument or relay a reverse wave at the proper moment to counteract that wandering zero. I have previously seen the apparatus and seen the results of its working, but I have never until this evening had the pleasure of seeing it in operation. I have heard many accounts of it and understand the principle upon which it is worked, but when I saw how the principle of rotation acted in overcoming friction on the relay tongue for the first time, I was astonished at the result, and delighted to see that the ingenious application of this principle had opened up the possibility of relaying on cables. I think I speak the feelings of every one here, especially of the cable electricians, when I say that they are deeply indebted to Mr. Brown not only for having perfected his apparatus as he has, and overcome great difficulties in so doing, but for bringing the matter before us in such a clear, concise and scientific manner as he has done. Mr. Wilkinson.

Professor AYRTON: I would like to ask Mr. Wilkinson one question. He said the Company rather liked the blurs and the absence of ripples. The question is not so much—if I may say so with every respect—what he would like, but what the instrument likes which has to produce the perforated slip to be used for sending the message along a land line. Supposing you did not put in the ripples, how could you automatically produce the slip which Mr. Brown showed us was produced at the other end, and how could you solve the problem which he has solved, namely, to receive a submarine cable message and transmit it along a land line in the ordinary Morse way? Professor Ayrton.

Mr. WILKINSON: I have much pleasure in answering that question. In the first place the land line is a very small matter in cable work and is usually connected to and treated as part of the cable. The great problem has been to transmit the message from one cable to another cable. The land lines were merely five or ten miles, where the cables are thousands. I do not look upon it in that light at all. I say this, that if Mr. Brown had given us the same instrument without the ripples, he could have transmitted messages from ocean to ocean precisely at the same speeds as he does now and without introducing the ripples. Mr. Wilkinson.

Mr. W. M. MORDEY: As I had ten years' experience in telegraphy before I was connected with electrical engineering, this paper interests me very much. I think it is an admirable example of the application of electrical engineering to telegraphy. I might tell you a little story about Mr. Brown. He was, as I suppose many of you know, engaged in electrical engineering at Messrs. Crompton's works. Three or four years ago he came to me and said he thought telegraphy offered a much better scope than electrical engineering. He therefore resigned his position at Crompton's, went in for the study of telegraphy, and we see to-night the result. I knew something of Mr. Brown before he took up telegraphy, and I was pretty sure he would achieve something useful, but I did not think he would advance so rapidly as he has done. Not long after that he asked me to come and see this apparatus working in the laboratory of Messrs. Clark, Ford and Taylor. I need hardly say I was delighted with it. I think it is one of the most beautiful inventions in telegraphy we have had for many years. People have Mr. Mordey.

Mr. Mordey. been working for the past 30 years on cable relaying; I do not think any one has practically succeeded before. It is clear the author has been greatly assisted by the experience gained in heavy engineering. I mention this because it shows we ought not to separate the two branches. It illustrates the importance, to those engaged in telegraphic work, of making as close a study as possible of the actions that take place in transformers, dynamos, and heavier apparatus. One cannot see much of the lighter kinds of apparatus without feeling that they could be improved by people who brought to bear on their design experience gained in the knowledge of things where larger amounts of power are dealt with. Two things in this paper strike one as very beautiful inventions. The drum relay is one. I suppose we all knew more or less in principle that by keeping one body in movement another that was in contact with it would have less friction, but it is a long way from that to making this application. No one can fail to be impressed, who knows the feeble effect obtained from a siphon recorder, and then sees this application by which a freely moving contact is obtained capable of transmitting a considerable current without any difficulty. It is very interesting to see the free movement of the contact point when the drum is running, and to see the movement cease when the drum stops. I think it probable that Mr. Brown got his idea for this device from observing—as we must all have done—that when a dynamo is running, a little pressure on the end of the shaft will suffice to move it backwards and forwards although it may weigh hundreds of pounds. When stationary we cannot move it at all. The second thing is the magnifying relay. It is a great feat to make a syphon-recorder galvanometer—a thing with a tenth of a fly-power—move a coil in an alternate-current field in such a way that the coil acts as the secondary of a transformer and enables a dynamo to deliver sufficient energy into the circuit. I think it is one of the most beautifully simple things that has ever been introduced in electro-magnetics. We have not to congratulate Mr. Brown merely on an invention or an idea; we have to congratulate him on having had the energy and perseverance to work this thing out to a practical success; and on having done it in such a short time. I hope we shall soon have other examples of his work before the Institution.

Mr. Clinker. Mr. R. C. CLINKER (*communicated*): Mr. Brown, at the end of his interesting paper, makes a suggestion as to the use of an instrument similar to his magnifying relay for measuring self-induction and capacity.

A month or two ago, I attempted to measure the self-induction of the suspended coil of a deflecting wattmeter employing this principle. The wattmeter experimented on was one of the Weston type. As mutual induction exists between fixed and moving coils when the pointer is at zero, it follows that a current passed through the fixed coil will induce an e.m.f. in the moving coil. If the latter be short-circuited (the series non-inductive resistance being cut out) a current will flow in the circuit. Were there no self-induction in the coil, the mean torque in one direction produced by this induced current would be zero, as the two currents would be in exact quadrature. Self-induction, however, causes a lag in the induced current, and produces a

torque in such a direction as to move the pointer up the scale. In the tests made, the following was the method of procedure. The resistance of the moving coil having been measured, a known current at known frequency, and having as nearly as possible a sine law of variation, was passed through the fixed coil and the deflection noted. The resistance of the moving coil circuit was then increased by a known amount, and the current in the fixed coil increased so as to give the same deflection as before, *i.e.*, the same torque. Mr. Clinker

From the known values of resistances and currents, the inductance of the moving coil could be deduced.

The results did not agree at all well with those obtained by other means, the value of L coming out much too high. No satisfactory reason for the discrepancy was found at the time, but I hope at some future time to repeat the tests more carefully.

A neater method of obtaining the same result would be to close the moving coil circuit with a condenser, and adjust the capacity or frequency until no deflection was obtained, when we should have $L = \frac{1}{p^2 K}$, where $p = 2\pi \times$ cycles per sec., and $K =$ capacity in farads. This, however, would require a condenser with a capacity of the order of 1,000 microfarads or so.

Mr. S. G. Brown (*in reply*): I must thank Professor Ayrton for the kind remarks that he made about the instrument. He pointed out the difficulty of interpolating the signals, as he said the automatic transmitter and the interpolator must run in approximate synchronism. As the speed of signalling gets higher and higher as we approach, and even pass, the speed of the siphon recorder, the possible difference between the two instruments gets less, so that you can imagine, by forcing the instruments to an extreme point, there will be no difference of speed left. Mr. Brown.

It was mentioned also in connection with the rotary drum that vibration would effect the same work as the sliding contact. This vibration question of relays has been worked out very fully by Delany, who has done a great deal in cable telegraphy in striving to make a practical cable relay. But the impossibility of working with vibration of any kind is that the contact, when it strikes the table or the plate as the point goes down, is so exceedingly short that practically no current passes. In all these cases we must remember that there is always a film of oxide forming on the metals, so that when they are actually hammered together they need not make a metallic contact.

In connection with the magnifying relay, I have practically worked out and tried in one form or another two distinct types. The one with the alternating current, that pumps energy into a suspended coil, seems, so far as I have thought about it, to be very much the best. I have most carefully calculated the effect of a dynamo, and it comes out to this. I find in designing such an instrument that the loss in the iron might be very considerable when worked with feeble forces. When iron is used with currents such as we get at the ends of cables, the molecules act very slowly; the curve of magnetism being shown in Fig. A.

Mr. Brown. We must be working down at the extreme end of curve X; the permeability of the iron, is, as I have mentioned, about 150. In dealing with a relay of the dynamo form, we have to take into consideration the power required to magnetise the mass of iron of the field magnets. To reduce this, I arranged the pole-pieces in the form of a magnetic balance (Fig. B).

The dynamo magnifier in this case had two pole-pieces, both excited and opposing each other; the cable currents were arranged to weaken one pair of pole-pieces and to strengthen the other, altering the distribution of the lines only. The speed was almost 2,000 revolutions a minute. In calculating the instrument, it turned out that the great controlling point was the air-gap. As the air-gap between the iron poles and the armature controlled everything, it was naturally impos-

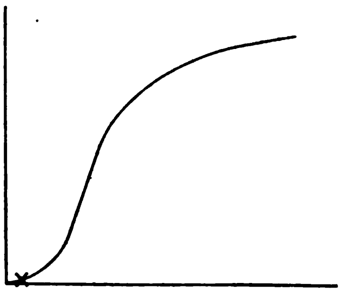


FIG. A.

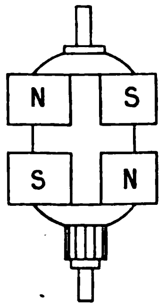


FIG. B.

sible to make the instrument, as Professor Ayrton said he had originally tried to make it, of air only, omitting the iron.

In the magnifying relay, Professor Ayrton has pointed out, you cannot have the suspended coil possessing only resistance; there must be a certain amount of self-induction. Self-induction is the cutting of magnetic lines generated by the coil from the induced currents. As the reluctance of the magnetic circuit of the coil would be very great, self-induction would be very small, but it can be entirely neutralised by a shunt of capacity—a fraction of a microfarad being found in practice quite sufficient. It is marvellous to watch the increase in the vibration of the suspended coil by putting induction in the circuit, and the slackening of the coil as capacity is plugged in.

With reference to Mr. Gavey's remarks, I have had the pleasure of meeting Mr. Donald Murray on two or three occasions, and I also had the pleasure of seeing Mr. Murray's extraordinary apparatus working at the Post Office. I do not think it is quite so complicated as the apparatus I have on view, but I think very nearly so.

Points have been raised about the interpolators. Some have thought that this was the main object of the invention, but the difficulty primarily was to get a relay to receive with these feeble currents from the cable, and

Mr. Brown.

then after that to be able to send on by a suitable instrument. We send on the signals by the rotation of a small clutch, and the clutch revolves twice or three times just as easily as it does once, so it might have been difficult to design an instrument of this class that did not interpolate.

Mr. Judd in his remarks mentioned the effect of tropical climates on the instrument. The difficulty has been the oxidation of the metal.

Mr. Sullivan mentioned the "butt" contact. Of course, as every one knows, there is a great deal of difficulty with butt contacts in relays for long cables, except at the lowest speeds, because you require, from the nature of things, a certain pressure to break down the insulating film on the metal, but you can get this pressure as I have got it, by sufficiently shortening the tongue, bringing the pointer near the point of suspension.

With regard to the length of cable that drum relays have been worked over, I have worked them over cables as long as the new Pacific which they are laying at the present time, and the speeds of working are about the same as the ordinary siphon recorder speeds. [Mr. SULLIVAN: Do you always use the interpolator for long cables?] We can use the interpolator, or as in Fig. 5 on page 1069, I have shown that the interpolator can be dispensed with. Slip A shows the signals without the interpolator, and slip C shows the same conditions with a hand key as transmitter; the interpolator is not necessary by any means. You can work the translation by a hand key as well as by an automatic transmitter, and you can send these signals on by means of a couple of sounders in place of the interpolator. The signals are squared up at the far station by means of a magnetic shunt.

I thank Mr. Mordey for his remarks. I have had a little acquaintance with heavy engineering. Some of my ideas, especially with regard to the magnifying relay, must have been picked up in connection with alternating-current machinery. I think every one of us must have noticed dynamos with the armatures rocking backwards and forwards under the brushes, so as to prevent grooving of the commutator, and it struck me that I might use that for the purposes of the relay.

The President

The PRESIDENT: Gentlemen, after the very hearty manner in which Mr. Brown has been complimented by every speaker who has joined in the discussion, I feel that it is almost superfluous for me to ask you to pass a very hearty vote of thanks to him for his paper. The admirable instrument that he has placed before us is undoubtedly the outcome of much thought and consideration, combined with a careful study of the principles of electrical engineering. The paper has been an extremely interesting one—perhaps more so than usual in consequence of its being the only paper we have had this session on a telegraphic subject. I am sure you will join with me in hearty thanks and congratulations to Mr. Brown for his admirable paper.

[The vote was carried by acclamation.]

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members:

Sydney Holmwood Holden.
Cuthbert Jeffryes Sutherland.

Associate Members:

James Meredith Austin.
Alan Randall Bell.
Frederick Arthur Bond.
Thomas Charles Hement.

Associates:

Charles Barnard Burdon.
Herbert Dean.
Charles Hustwick Ellison.
Victor Graff.
William Henderson.
Ernest Long.
Hubert Samuel Marsden.
William Mead.
Wilhelm Theodor Meier.
George Alfred Neild.
Harold Bernard Sale.
Edward Arthur Shaw.
Charles William Webster.
Thomas Wray.

Students:

John Aspin.
Roland Lennox Davies.
James Henry Forster.
Alfred Richard Harris.
Horace Morley Lawson.
Herbert Samuel Street.

The Three-Hundred and Seventy-Ninth Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 8th, 1902—Mr. WILLIAM E. LANGDON, President, in the Chair.

The Minutes of the Ordinary General Meeting held on May 1, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Robert Martill Wilson.

From the class of Students to that of Associates—

Harry Melville Dowsett. | R. Mondel Moberly.
George N. M. Tyrrell.

Messrs. A. Schneider and E. B. Vignoles were appointed scrutineers of the ballot for the election of new members.

Donations to the Building Fund were announced as having been received since the last meeting from Messrs. J. Grant and C. E. Wilson, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I have to announce that the report of the proceedings of the Committee appointed to inquire into Electrical Legislation will be obtainable by members on application to the Secretary, if applications are made prior to June 30th. It is necessary that applications should be received by the Secretary prior to that date in order that he may determine the number of copies that shall be printed.

APPEAL FOR BUILDING FUND.

I have also to inform you, gentlemen, that the Building Fund has now reached the amount of £10,000. In making this announcement I am desirous, in the first place, to congratulate our Treasurer, Prof. Ayrton, on the amount having reached this sum—a sum he has been very anxious it should attain for some time past, and which I am sure will afford him as much pleasure as it will the other members of the Institution. I am also anxious to take this opportunity to seek your

liberal support of this fund. We have now got together a nucleus of £10,000. £10,000, of course, is not a large sum towards the object which we have in view, that object being the provision of an Institution Building — a building which would be a truly representative building of the Institution of Electrical Engineers. The future before Electrical Engineers is undoubtedly a large one, and we may look forward to the Institution becoming not only a numerous and popular, but also a very influential institution ; and it is very desirable, I think, in the interests of the Institution as representative of the profession that we should all aim to gather together the means of providing a suitable representative building for the members generally. Such a building will be of immense advantage to the Institution. At the present time we are labouring under difficulties in our administration in consequence of the rapid growth of the Institution, the rapid expansion in the number of members, and the amount of work consequently devolving upon the administrative portion of the Institution. It is hardly to be hoped that we shall gather together the means of obtaining a building which will be entirely suitable to our wants for some time to come; but if we do not progress faster than we have done in the past, having regard to the fact that we have been in existence some thirty years, and that during that period the amount which has been accumulated has been only £10,000, it will be many years before we shall get our building. I am therefore very anxious, gentlemen, to appeal to all members of the Institution that they should put their shoulders to the wheel and try to help this fund. We are now something over 4,000 strong (nearer 4,500). If every member of the Institution were to contribute annually, say 10s. a year, we should add some £2,000 or £3,000 a year to this fund. But I think we may go far beyond that, for I am quite sure there are many members who would be very glad indeed to contribute a larger sum than that. If we averaged a guinea a year from each member, we should soon be able to amass a sum of money that would place us in possession of that which we want. I appeal to every gentleman here to mention the matter to his friends; to every member of the Institution, whether resident in London, the provinces, or abroad. The Institution when once it becomes established will be a place of reference to those who are abroad, in the Colonies, or away from home. It is true that Londoners will have a greater advantage in that respect, but you must remember that a man who is resident in London at the present time may be resident in the Colonies next year, and so the advantage of such a building will in fact be reaped by the whole Institution.

In tendering these remarks to you, I hope it will be understood that I do not in any way forget the great services that have been rendered to the Institution by the Institution of Civil Engineers. We have received at their hands the greatest courtesy and the greatest kindness, and I am sure every member of the Institution will always be prepared to recognise those services. I trust, gentlemen, that all of you will do your utmost to contribute towards this fund, so that it may grow in the future much faster than has been the case in the past.

The discussion on the Draft Form of General Conditions submitted to the meeting on April 24th was resumed, Messrs. G. H. Nisbett, Stuart Russell, C. C. Hawkins, J. Kingsbury, J. N. Shoolbred, W. B. Esson, W. E. Gray, N. Gunz, and C. H. Yeaman taking part.

Mr. R. Hammond, as Reporter to the Committee, then replied to points raised in the discussion.

The PRESIDENT, having stated that the report of the discussion would receive careful consideration by the committee, announced that the scrutineers declared the following to have been duly elected :—

Members :

Thomas J. Fleming.
William S. Hulse.

Associate Members :

Horace David Boden How.
Arthur John Fippard.
James Pattison Kemp.
Harold Charles King.
Andrew Frederick Rock.

Associates :

William Snowley Entwistle.
Charles Henry Haddrell.
Alfred Noel Hazlehurst.
Robert Maynard Leonard.
Alfred Mansfield.
Charles Frederick Bertram Marshall.
Frank Lindsey Moysey.

Students :

James Gray.
Percy Hugo Harding.
Mario A. Stoppoloni.
William Lawrence Turner.

The Three Hundred and Eightieth Ordinary General Meeting of the Institution was held at the Rooms of the Society of Arts, Adelphi, London, on Thursday evening, May 15th, 1902—Mr. W. E. LANGDON, President, in the Chair.

The minutes of the Ordinary General Meeting held on May 8th, 1902, were read and confirmed.

The following transfers were announced as having been approved by the Council:—

From the class of Associates to that of Associate Members—

George Frederick Lewis Alexander.

From the class of Students to that of Associates—

James Cameron Smail.

Messrs W. Henderson and A. H. Hunt were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from the Incorporated Association of Municipal and County Engineers and the Royal Meteorological Society; to the *Building Fund* from Mr. W. del Mar and Mr. J. E. Stewart; and to the *Benevolent Fund* from Mr. S. H. Holden, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have now, gentlemen, to announce that the Council has unanimously elected Signor Antonio Pacinotti as an Honorary Member of the Institution, and I have the pleasure also of reading a letter received from Signor Pacinotti by the Secretary.

(*Translation from the Italian.*)

"PISA, *May*, 9, 1902.

"*To the Secretary of the Institution of Electrical Engineers.*

"It is truly a very high honour that the Council of the Institution of Electrical Engineers paid me in deciding to ask me to accept election as one of its Honorary Members.

"I have never forgotten the kind interest shown by the Electrical Engineers of London in my models of dynamo-electric machines at the Paris Exhibition of 1881, and particularly at the meeting on the evening of the 24th of September. To me it would be a great honour, which I

should gratefully accept, to form part of your illustrious Society as an ordinary member.

"But if on the grounds of age, rather than through any merit, the Council should insist on my being an Honorary Member, I can only say that no honour bestowed on me could make me feel superior to any of the illustrious Members of the Institution of Electrical Engineers.

"I have the honour to be,

"Yours truly,

"(Signed) Antonio Pacinotti."

ELECTRICAL TRACTION ON STEAM RAILWAYS IN ITALY.

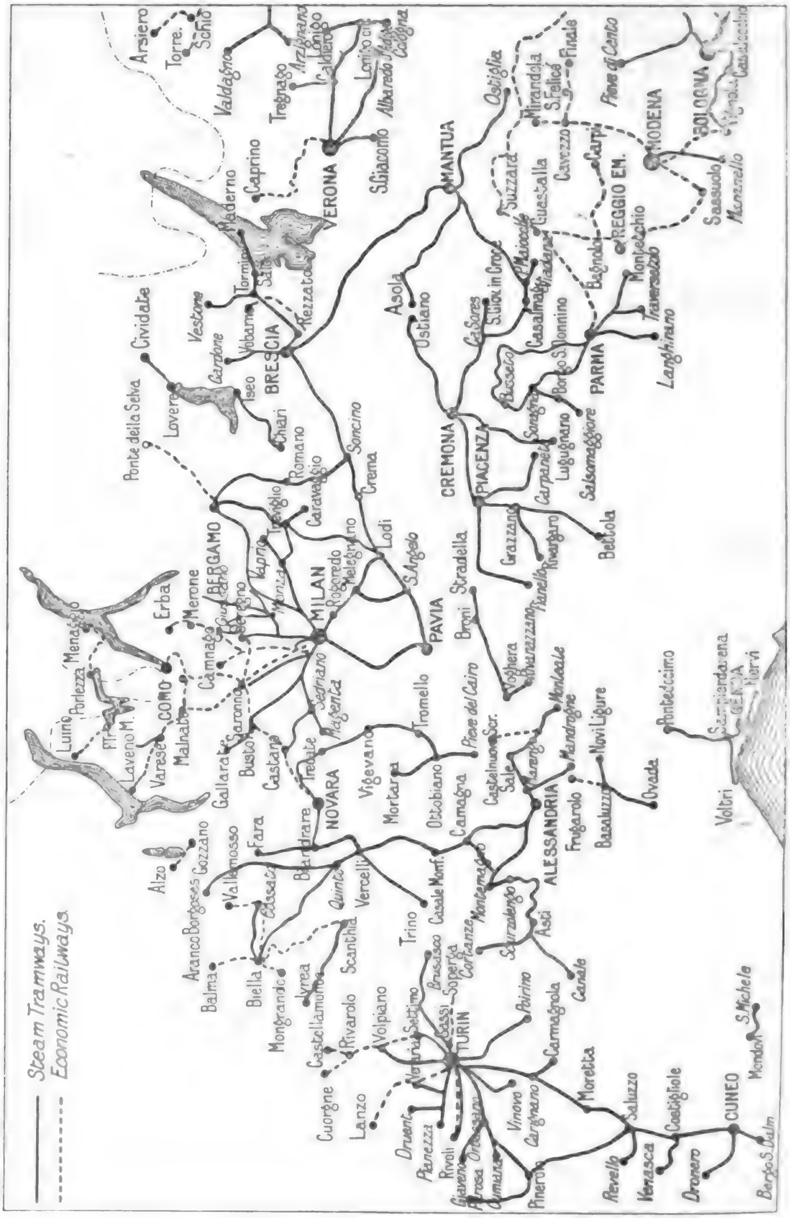
By Professor C. A. Carus-Wilson, M.A., Member.

Italian Railways.

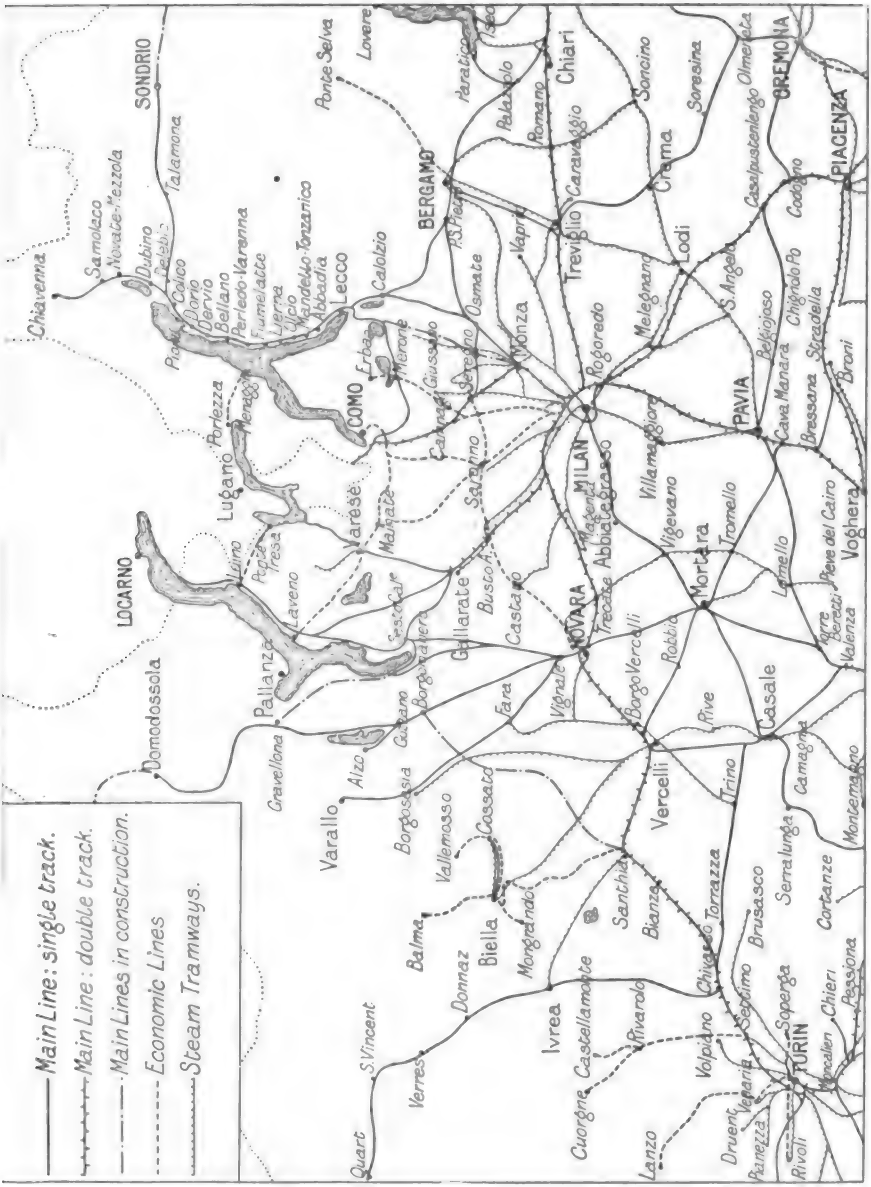
The Adriatica and the Mediterranean Railway Companies together work eighty per cent. of the railways in Italy, the former serving the whole of eastern Italy from Venice to Brindisi, and the latter the whole of western Italy from Turin to the extreme south. The two systems have their chief connecting points at Milan, Florence, Rome and Naples. The number of miles of line worked by each Company is about the same, nearly 3,690 miles by the Mediterranean and 3,620 by the Adriatica. Each of these Companies, therefore, works about as many miles of line as the Great Western and the Great Northern Companies put together.

The railways are now being worked under an arrangement with the Italian Government, by which the Government gives the Companies an annual subsidy in return for a certain proportion of the receipts. For the year 1900 the Adriatica Company received from the Government a subsidy of £2,166,000, while it paid to the Government a sum equal to 40 per cent. of the total receipts, amounting to £2,040,000, the balance to the credit of the Company being £126,000. This arrangement comes to an end in 1905, when the Government has the option either of buying out the Companies or of coming to a fresh arrangement with them.

For a long time past the Italian railways have been



Map A.—Map showing Network of Steam Tramways and Economic Lines in Northern Italy.



Map B.—Map showing Railway Connections in the neighbourhood of Milan.

suffering from the competition of tramways and economic lines, which have provided a cheaper and more frequent service, seriously affecting the traffic on the main lines in spite of every effort made to minimise the injury thus caused. The map on page 1092 shows the network of steam tramways and economic lines that has spread over northern Italy; these not only radiate from most of the large towns, such as Milan, Turin, Verona, etc., but also serve as links to connect one town with another, as for instance the line connecting Milan with Pavia, which is twenty miles long, and that connecting Brescia and Mantua, which is forty-three miles long. The railway companies have come to the conclusion that the remedy for this competition lies in providing, by means of electricity, a service of short trains running frequently at high speeds. This paper will contain an account, written from an economic rather than from a technical standpoint, of what is being done towards carrying out this object, with some comparisons between the conditions of railway working in Italy and in England.

THE ADRIATICA RAILWAY.

The Adriatica Railway Company has already equipped electrically that portion of its system running from Lecco to Colico, and thence to Sondrio and to Chiavenna (see map on page 1093). The intention is to extend the system ultimately to Milan. Meanwhile the electrically driven trains are to work their own way as far south as Lecco, and to be hauled thence to Milan by steam locomotives. Trains are now running experimentally, but not yet in actual service.

The total distance at present electrified amounts to 66 miles, all of single track, a large proportion between Lecco and Colico being in tunnel. A profile of the line is given in Figure 1. The hydraulic power-house with turbines of 6,000 horse-power is at Morbegno, water being taken from the river Adda. Three-phase current is generated at 22,000 volts and carried by overhead conductors to nine transformer stations, where it is transformed down to 3,000 volts and taken to the two trolley wires, the rail forming the third conductor, and thence direct to polyphase motors on the cars.

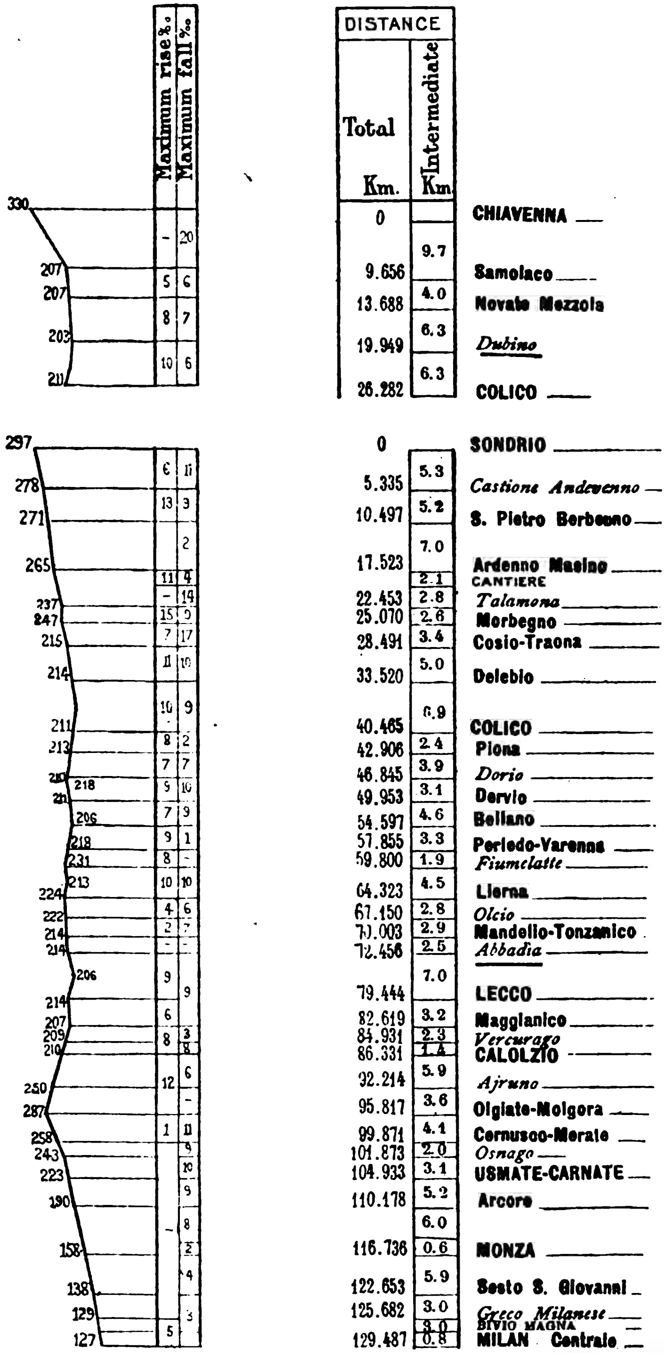


FIG. 1.—Profile of Lecco-Colico Line.

The motor cars, of which a view is given in Fig. 2, are 57 feet long, weigh 53 tons unloaded, and have seating accommodation for 56 passengers. Each car is provided with two high-speed motors of 150 H.P., and two low-speed motors of 75 H.P. each, weighing 3·8 tons and driving direct without gearing. Full speed is 37 miles an hour. The four motors are used in cascade connection at starting: at half-speed the two low-speed motors are switched out, and the car is driven by the two high-speed motors alone at full speed. On all grades over one per cent. the motors are connected in cascade and the speed thus halved. The trailers used are passenger carriages of the ordinary type. The goods traffic is to be hauled by electric locomotives.

The Company is introducing a new "economic" system for working the line, by which they hope to reduce the traffic expenses, eighty per cent. of which is accounted for by the wages and salaries of the personnel at the stations. This system has been in operation on other parts of the Company's lines and has been found to work well, as, for instance, on the section of line, 27 miles long, between Bologna and St. Felice, part of the projected line from Bologna to Verona. In this system the stations are divided into "control" stations and "section" stations. On the Lecco line there are 6 of the former and 11 of the latter. The responsibility for the control of the traffic rests with the personnel at the "control" stations, the agents at the "section" stations having no direct responsibility for the safe conduct of the traffic which depends entirely on an automatic block system operated by an electrical apparatus which the agent has to attend to and keep in working order. Each "section" station is in telephonic communication with the nearest "control" station, to which all questions relating to rates, regulations, etc., can be referred. By this means a considerable reduction in the expense of the personnel at the stations is rendered possible.

The block system employed is the Webb and Thompson Staff system, supplemented by an electric interlocking apparatus invented by Signor Olper, the Controller of Telegraphs in the Adriatica Railway Company, combined with an arrangement by which the trolley line at every station is divided into sections, each controlled by a switch

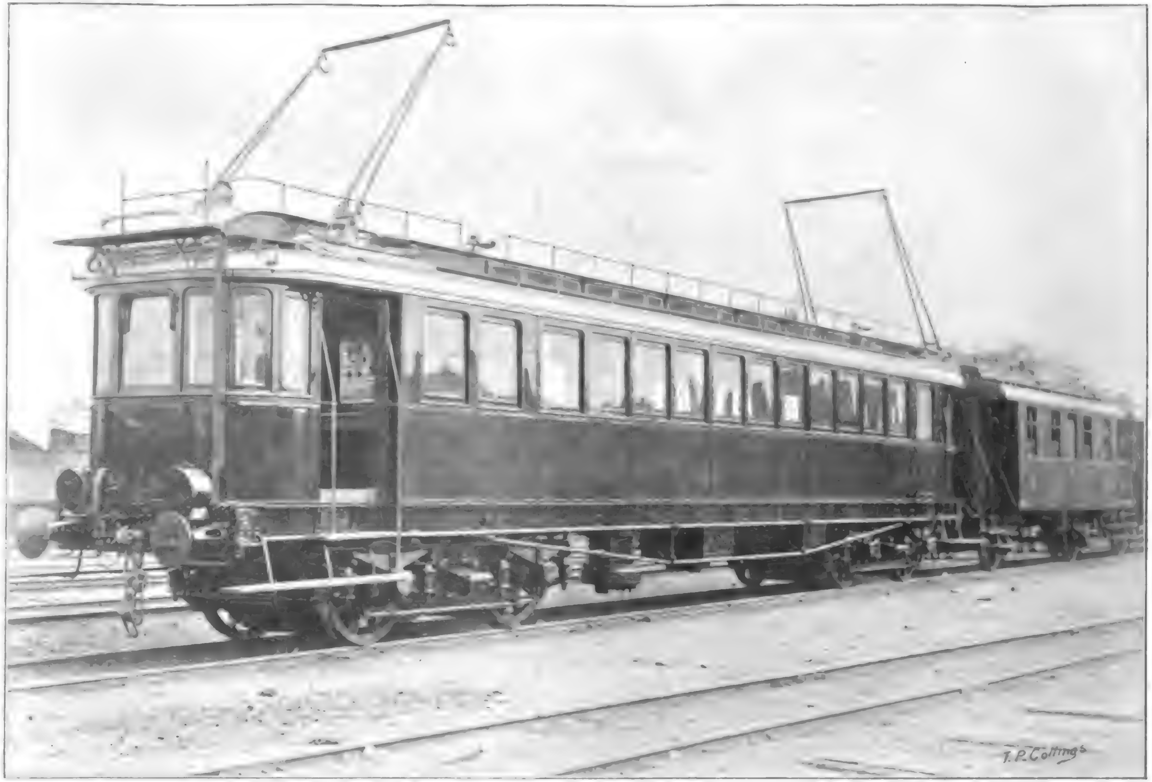
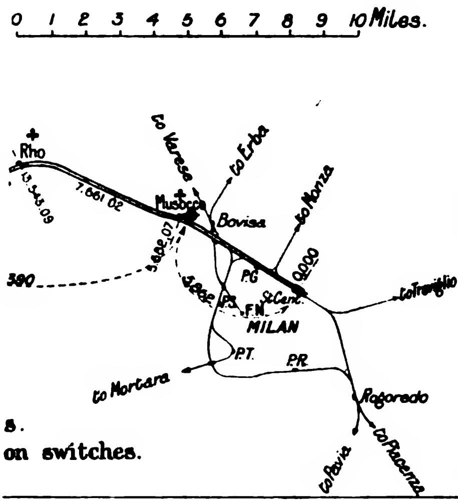


FIG. 2.—Motor Car used on the Lecco-Colico Line.



s.

on switches.

the opening and closing of which takes place simultaneously with the movement of the corresponding signal, so that it is impossible for a train to run on to a section against signals.

THE MEDITERRANEAN RAILWAY.

The Mediterranean Railway Company is equipping electrically the whole of the line from Milan to Gallarate and thence to Varese, Porto Ceresio, Laveno, and Arona. Some idea of the importance of the change now in progress may be gained from the fact that the passenger receipts from these sections of line amount to about two per cent. of the receipts for the whole Mediterranean system.

The total length of line is 81 miles, made up of sections as given in Table V. Of the whole distance all is of single track except the length from Milan to Gallarate, which is of double track. The maximum grades and minimum curves are given in the table. A profile of the line is given in Figure 3, and a plan in Figure 4.

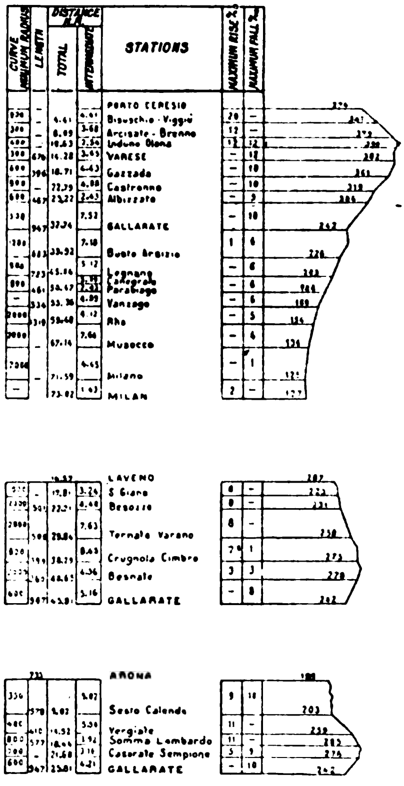


FIG. 4.—Plan and Profile of the Milan-Varese Line.

The power-house is at Tornavento, about seven miles from Gallarate. Current is at present being supplied from a steam-generating plant, but a water-driven plant is in course of construction close to the steam power-house from which the whole line will ultimately be worked. Turbines of a

total of 11,000 H.P. will be driven by water taken from the river Ticino.

The power is transmitted as three-phase current at 12,000 volts to seven sub-stations along the line, where the pressure is reduced from 11,000 to 420 volts and the current is transformed in rotary converters to direct current at 650 volts. From the sub-stations the current is taken to an insulated third rail, as shown in Figure 5.

The motor-cars on the Varese line, shown in Figure 6, weigh 40 tons unloaded, and have accommodation for 63 passengers seated and 12 standing. Each motor-car is driven by four 150 H.P. motors, on the usual one-hour rating, and is geared with a 3 to 1 ratio to 41-inch driving wheels. Full speed on a level is 56 miles an hour. Each motor weighs 2·5 tons. The trailers weigh 27 tons empty, and have accommodation for 63 passengers seated and 27 standing. The goods traffic is to be hauled by electric locomotives.

The electric trains are now running and in regular operation as far as Varese, though the service of trains as contemplated is not yet complete.

TABLE I.

Comparing the Weight, Power, and Dimensions of the Polyphase Motor-Cars on the Lecco Line with the Direct-Current Motor-Cars on the Varese Line.

	Total Weight Empty.	Length of Frames.	Seats.	No. of Motors.	Maximum H.P. of Each.	Total Maximum H.P.	Weight of Four Motors.	Full Speed on Level.
	Tons.	Feet.					Tons.	M.P.H.
Varese...	40	52	63	4	150	600	10	56
Lecco ...	53	57	56	4	2 of 150 2 of 75	300	15·2	37

Working Expenses and Receipts.

The working expenses of the Italian railways are given in Table II. These figures actually refer to the Adriatica Railway, but as the corresponding figures for the Mediter-

FIG. 5.—View of High-Tension and Third-Rail Construction on the Milan-Varese Line.

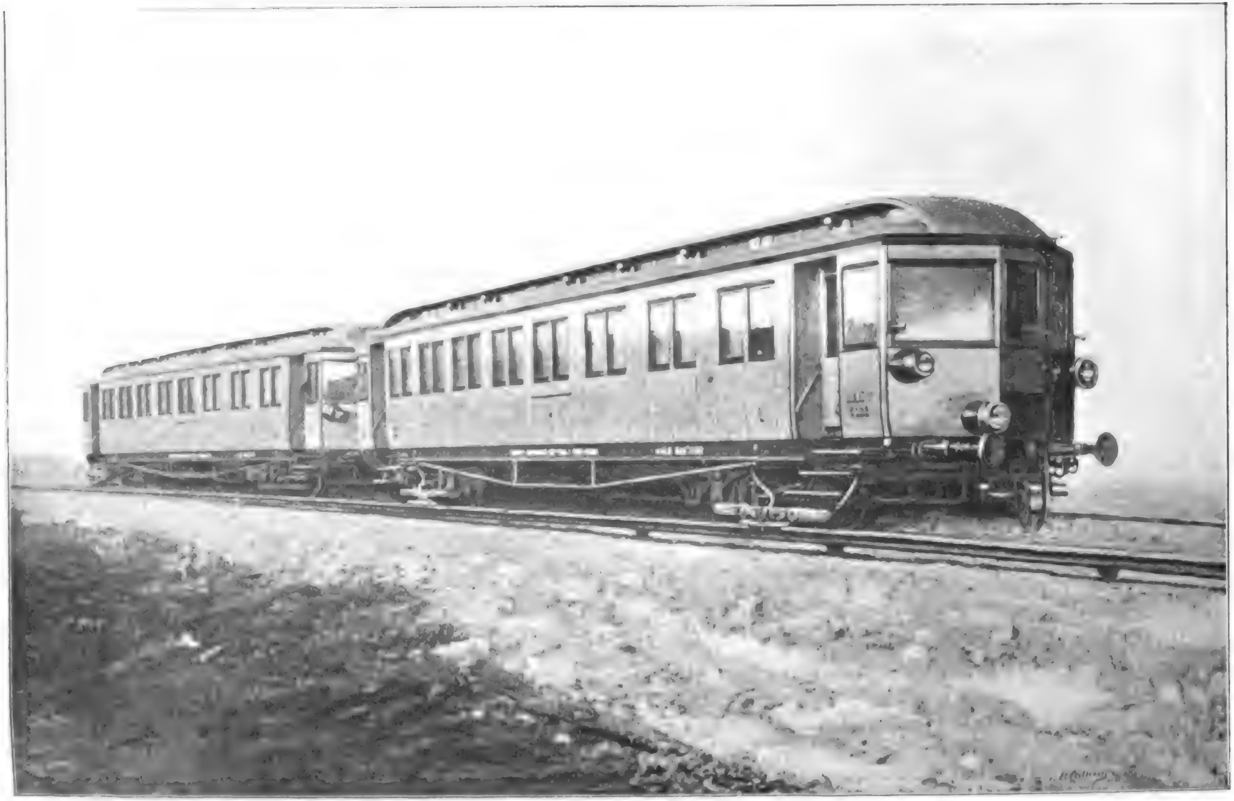


FIG. 6. -Motor Car Train used on the Milan-Varese Line.

ranean Railway are almost the same, they may be taken as representing the cost of running on either of the great systems. To afford a comparison, the figures for the cost of running an English railway are placed in the same table.

A distinction has been made between those expenses which do and those which do not vary with the number of trains run. Thus, to the locomotive expenses comprising wages of driver, water, oil, and repairs, have been added the cost of conductors' wages and carriage repairs. All these expenses vary with the number of trains run, and are therefore dealt with apart from those, such as the maintenance of the line, which do not so vary.

TABLE II.

RUNNING EXPENSES PER PASSENGER TRAIN-MILE.

		ENGLISH.	ITALIAN.
1	Coal	1·72 pence	5·30 pence
2	Wages of driver and stoker ...	3·81 ,,	3·18 ,,
3	Wages of conductor	1·52 ,,	2·08 ,,
4	Water, oil, etc....	0·77 ,,	0·60 ,,
5	Repairs, locomotives	2·39 ,,	3·52 ,,
6	Repairs, carriages	2·83 ,,	6·01 ,,
	Total	13·04 ,,	20·69 ,,

Note.—English items 2, 4, 5 and 6 from Official Returns for the Great Northern Railway for 1900.

Italian items 2, 3, 4, 5 and 6 from Official Returns of the Adriatica Company for 1899.

Item 3 under English costs, obtained by taking the wages of driver, firemen, and conductor in the proportion of 42s., 22s., and 25s.

The coal consumption on an English railway is taken at 40 pounds per train-mile, and the cost at 8s. per ton.

The actual consumption of coal on the locomotive on the Italian railways is given in the Official Reports as 41 pounds per train-mile. The statistics draw no distinction between the weight of an average goods train

and that of an average passenger train, but the passenger train-mileage is stated to be 68 per cent. of the whole train-mileage. Taking the weight of coal per passenger train-mile to be 70 per cent. of that per goods train, the coal consumption per passenger train-mile would be 36 pounds, which brings the cost, at 27s. per ton—the price paid in 1899—to 5·3 pence per train-mile.

TABLE III.

Giving the Receipts and Expenses per Mile.

	English.	Italian.
Fixed Expenses.	£	£
Maintenance of the line	535	132
Traffic expenses	1,350	236
General expenses	537	53
Total	£2,422	£421
Running expenses	£1,750	£699
Receipts.	£	£
Passenger traffic	2,640	640
Goods and miscellaneous	3,820	965
Total	£6,460	£1,605
Expenses in per cent. of receipts ...	65	70

Note.—The figures in this Table are obtained from the same sources as those in Table II. "Per mile" means per mile of line regardless of the number of parallel tracks.

In order to compare the running expenses with the fixed expenses, they have both been reduced to pounds per mile per annum, and placed in Table III., together with the receipts estimated in the same way. The running expenses of an Italian railway constitute a far larger proportion of the total expenses than is the case on an English railway, the percentages being 62 in the former case and 42 in the latter. The proportion of passenger to goods receipts is nearly the same, while the sum of all the expenses is 70 per cent. of the receipts in Italy and 65 per cent. in England.

The receipts given for the Italian railways refer to the Adriatica system as a whole, and are greater than the receipts of the lines that are now being electrified. Thus the passenger receipts for the section Lecco-Colico are only £380 per mile per annum, for the section Sondrio-Chiavenna £220, whereas for the section Milan-Varese-Arona-Laveno the passenger receipts are £600 per mile per annum. The most profitable section in the Mediterranean Company's system is the line from Milan to Genoa, which is six times as profitable as the average for the whole system; the most profitable on the Adriatica system is the line from Milan to Como, the continuation of the St. Gothard railway, a line common to the two systems, and yielding to each railway three-and-a-half times the average receipts per mile on the Mediterranean.

The expenses of maintenance, traffic, and central administration on an Italian railway amount to £421 per mile per annum, about one-sixth of what it is in England. Of the item for traffic expenses in Italy, £213 per mile is for stations expenses, out of which again £170 per mile is for the personnel at the stations. The Adriatica Company is seeking to reduce this item by the adoption of the "economic" system of working the line referred to above.

Fares.

The fares charged on the various railway lines in Italy are given in Table IV. Column A gives the through express fares on the main lines, and column B the fares for the so-called omnibus trains which stop at all stations. Column C gives the reduced rates charged for omnibus trains on certain sections of the main lines, those, namely, where the competition with the tramways and economic lines is most keenly felt. Thus on the lines Milan-Gallarate-Varese, where there is direct competition, reduced rates are charged. The rates in the economic lines are given in column E, while the tramway rates will be found in column F. The rates in column E cover both omnibus and express trains, whereas the "reduced" rates are exclusively for omnibus trains, so that the main lines do not offer such a good service for the same money as the economic lines even at the reduced rates.

TABLE IV.

Showing the Passenger Fares, in Pence per Mile, Charged on the Different Italian Lines.

Lines ... ... Main. Economic. Tram.

Power ... ... Steam. Electric. Steam. Steam.

Service ... ... Exps. Omnbs. Exps. Omnbs. Exps. Omnbs. Omnbs.

Schedule speed (miles an hour) 25 16 45 25 25 16 9

Fares charged ... Exps. Ord. Redcd. Ordny. Ordny. Ordny.

	A.	B.	C.	D.	E.	F.
First Class ...	2·1	1·9	1·5	0·9	1·5	0·9
Second Class ...	1·4	1·3	1·0	—	1·0	0·7
Third Class ...	1·0	0·8	0·5	0·5	0·6	—

The Train Service.

The service of steam trains that formerly ran on the Milan-Varese line is given in Table V., with the time occupied in covering the different sections. This may be compared with the new service of electric trains, particulars of which are also given in the table. Thus on the line from Milan to Gallarate the schedule speed has been nearly doubled and the frequency increased 3·5-fold. On the line from Gallarate to Varese the speed has been increased 75 per cent. and the frequency about 4-fold. The old trains, hauled by steam locomotives, have been replaced by trains of about half their weight, consisting of motor-cars and trailers, the normal train consisting of one motor-car and one trailer, weighing together 67 tons unloaded, and capable of carrying 165 passengers, or about one-half the accommodation of the steam-driven trains. The carrying capacity of this portion of the line, in passenger miles, has thus been increased 75 per cent. Between Gallarate and Arona and between Varese and Porto Ceresio the speeds have not been increased on account of the grades, which are as much as 2 per cent., and the trains will run with the motors in permanent series connection.

TABLE V.

GIVING THE STEAM AND ELECTRIC TRAIN SERVICE ON THE MILAN-VARESE RAILWAY.

	Miles	Max. Grade.	Min. Curve Chains.	Trains each way per day.		Time in Minutes.	
		Per cent.		Steam.	Elect.	Steam.	Elect.
Milan to Gallarate	25·0	0·6	40	10	35	60	34
Gallarate to Varese	11·7	1·0	25	7	27	28	18
Gallarate to Laveno	19·4	0·8	30	6	8	81	50
Gallarate to Arona	16·0	1·1	17·5	5	8	45	45
Varese to Porto Ceresio ...	8·8	2·0	15	5	6	28	28

THE COST OF WORKING THE ELECTRIC SERVICE.

The cost of running the new electric service on the Milan-Varese line may be estimated approximately from the cost of working the old service, and is given in Table VI.

Coal.—The coal consumed per ton-mile in the steam generating plant, pending the completion of the hydraulic power-house, will probably be not much less than that used on a steam locomotive if the speed and rolling-stock is the same in both cases. Thus, as the weight of the electric trains is about half that of the old steam train, the coal used per train-mile will be halved. Possibly this assumption does not do justice to the economy of the electric system, but there is not sufficient data available to warrant a more favourable estimate being made.

The speed is, however, nearly doubled, so that if the same rolling-stock were used the tractive resistance, and hence the coal consumption, would be increased. But the type of rolling-stock is being improved, and short two-axle carriages are being replaced by long coaches running on bogies, so that the tractive resistance at the higher speed should not exceed that at the lower speed by more than 25 per cent., bringing the coal consumption to 23 pounds and the cost to 3·4 pence per train-mile.

(*Note.*—The Author learns from Signor Tremontani, the engineer of the Mediterranean Railway, that the coal con-

sumption for a service of trains consisting of one motor-car and two trailers is 28·5 pounds per train-mile. The weight of these trains is one-third greater than that estimated in the paper, as it was found necessary to add a second trailer on account of the increase in the traffic. This increase in the weight of the train would have brought the Author's figure for coal consumption up to 31 pounds per train-mile; his estimate, therefore, appears to be about 10 per cent. too high. At the present time only 20 trains per day are running each way between Milan and Gallarate, and 17 between Gallarate and Varese.)

Wages.—The driver and fireman are replaced by one motor-man at about half their combined wages, and, as the electric train is always ready to start up, a further saving of about 20 per cent. should be effected in comparison with a train hauled by a steam locomotive which has to spend a considerable time in the shed. These savings should reduce the item for locomotive wages to 40 per cent. of its former value—that is, to 1·27 pence per train-mile.

The item for conductors' wages will be reduced 20 per cent. owing to the saving of time mentioned above, and will be 1·67 pence per train-mile.

The wages at the generation station will amount to about £4,000 per annum: for a line 80 miles long, and with 28 trains per day each way, the cost would come to 0·58 pence per train-mile.

The wages at seven rotary sub-stations should not, together, exceed the wages at the generating station, making the cost for this item 0·58 pence per train-mile.

Water, Oil, etc.—The cost of water, which is 25 per cent. of that for water and oil combined, will be saved, reducing this item to 0·45 pence.

Repairs.—The cost of repairs will be reduced. On the City and South London Railway, during 1901, the cost of locomotive and generating repairs per train-mile, including wages and materials, was 38 per cent. of the locomotive repairs on the Great Northern Railway. Taking 50 per cent. of the cost of steam locomotive repairs, the cost of repairs for electric motors and generating stations would amount to 1·76 pence per train-mile.

As the electric trains are one-half the length of the steam trains, the carriage repairs per train-mile will be halved;

this item will thus be reduced to 3 pence per train-mile. The total cost of running would thus be reduced from 21 pence to 12 pence per train-mile.

TABLE VI.

SHOWING THE COMPARATIVE COST OF RUNNING AN ELECTRIC AND A STEAM LINE IN ITALY AND IN ENGLAND IN PENCE PER TRAIN-MILE.

	Italian.		English.	
	Steam.	Electricity.	Steam.	Electricity.
Trains each way per day ...	8	28	8	28
Coal	5·30	3·40	1·72	1·07
Wages of driver and stoker ...	3·18	1·27	3·81	1·52
Wages of conductor	2·08	1·67	1·52	1·22
Wages at generating station ...	—	0·58	—	0·58
Wages at rotary sub-stations ...	—	0·58	—	0·58
Water, oil, etc.	0·60	0·45	0·77	0·58
Repairs, motors, and generating station	3·52	1·76	2·39	1·20
Repairs, carriages	6·01	3·00	2·83	1·41
Total	20·69	12·71	13·04	8·16
Figure used in the paper ...	21·00	13·00	13·00	8·00

Estimate of Traffic.

The passenger traffic required to pay the expenses of the new electric service can now be estimated. On the Milan-Gallarate-Varese line the service is being increased from 8 to 28 trains per day, while the cost of running is reduced from 21 to 12 pence per train-mile. The cost per mile of line is thus increased from £510 to £1,110 per annum. To this must be added the interest on the capital expended in the electric installation. The total estimated cost is ten million francs, or £5,000 per mile. At 3½ per cent. this would add £175 per mile to the increased cost of running, making the total increase £775 per mile per annum. See Table VII.

The passenger receipts for this line, including the extensions to Arona and to Laveno, are £600 per mile per annum. Hence the passenger traffic must be increased by 129 per cent. to pay the interest and the increased cost of running. With transformer sub-stations the running expenses are decreased 5 per cent., and the increase of traffic must then be 114 per cent.

On the completion of the hydraulic power-station coal will no longer be used, and this item in the cost of running will be saved. The cost per train-mile will then be reduced to 9·31, or, say, to 9·5 pence, making the total increase in the expenses £475 per mile per annum, and the increase in the passenger traffic required to meet this increase 80 per cent., as compared with 129 per cent. for a steam plant. With transformer sub-stations the increase need only be 72 per cent. The value of water-power may therefore be represented by a reduction of 20 per cent. in the passenger traffic required to pay expenses.

TABLE VII.

SHOWING THE EXPENSES IN POUNDS PER MILE PER ANNUM OF RUNNING A STEAM SERVICE OF EIGHT TRAINS AND AN ELECTRIC SERVICE OF 28 TRAINS EACH WAY PER DAY IN ITALY AND IN ENGLAND.

	ITALY.			ENGLAND.	
Power used	Steam.	Electricity.		Steam.	Electricity
	Coal.	Coal.	Water.	Coal.	Coal.
Number of trains each way per day	8	28	28	8	28
Cost in pence per train-mile (¹)	21	13	9·5	13	8
	£	£	£	£	£
Running expenses	510	1,110	810	320	680
Interest	—	175	175	—	280
Total	510	1,285	985	320	960
Increase	—	775	475	—	640
Per cent. increase in traffic required to pay expenses	—	129	80	—	61

(¹) With rotary sub-stations.

On the Lecco line the service of steam trains was formerly about half as frequent as on the Varese line. The proportional increase in the number of electric train-miles will be about the same, so that the increase in the cost of running per mile of line, with transformer sub-stations, will be £150 per annum with water power. The capital expenditure has been about eight million francs, or £5,000 per mile, involving an interest charge of £175 per annum, which, together with the increase in the running expenses, brings the total increase to £325 per annum. The passenger receipts are here much less than on the Varese line, being £380 per mile per annum for the section Lecco-Colico, £220 for the section Colico-Sondrio-Chiavenna, and £330 per mile for the whole line. Thus an increase of £325 per annum will require an increase in the passenger traffic receipts of 128 per cent. The conditions of working an electric service on this line are therefore not quite so favourable as on the Varese line.

Reduction of Fares.

The extent to which a combination of reduced fares and increased travelling facilities augment traffic has long been made a subject of careful consideration by the Italian railway companies. For some time past the Adriatica Company has been investigating this question experimentally on the line connecting Bologna with St. Felice, referred to above. The experiment was made with cars driven by electric accumulators. The speed and the frequency of the trains were both doubled, and the fares reduced to 40 per cent. of their original amount. The result has been that the passenger traffic has increased five-fold, and the receipts have been doubled.

The fares on the new electric trains are given in Table IV., and are good for all trains whether express or omnibus. On the Milan-Varese line the reduced rates, as given in column C, have been available on omnibus trains only, express fares being charged on all express trains; about 20 per cent. of the total passenger receipts on this line being at the express rate, and 90 per cent. of the receipts from third-class passengers. If this proportion is maintained under the new conditions, the falling off in the receipts due

to the reduction in the fares would be about 20 per cent., if there were no increase in the traffic. It has already been shown that to pay the expenses of the new service at the old rates the traffic must be increased 80 per cent. if water-power is used, so that with the new rates the traffic must be rather more than doubled.

With the new electric service on the Milan-Varese line the minimum fare is still about the same as before, namely, a halfpenny a mile, but whereas formerly this rate only entitled a passenger to travel on an omnibus train, it now entitles him to travel by any of the express trains, the speed of these trains being twice what it was before, and the service three to four times as frequent, so that for those who formerly patronised the express trains the fares have been halved and the speed doubled. The speed of the omnibus trains is also doubled, but owing to the number of stops the saving in time is not more than 30 per cent.

The new service has been inaugurated by the railway company in confident expectation that the improved service will increase the amount of traffic to such an extent that the receipts, even at the lower rates, will more than pay the expenses.

Comparison of the Conditions of Running an Electric Service in England and in Italy.

It may be useful to compare the figures obtained above for the conversion of a steam to an electrically driven railway in Italy with those that would be obtained under similar conditions in England. If the reduction in the weight of the train, and the increase in the service are in the same proportion in the two cases, the proportionate reduction in the running expenses will also be the same. With this assumption the cost will be reduced from 13 to 8 pence per train-mile; the different items are given in Table VI. With a similar increase in the train service, namely, from 8 to 28 trains each way per day, the working expenses would be £680 per mile per annum, as compared with £320 with the former steam service, or an increase of £360 per mile. The electric installation would probably be more costly than that for the Italian lines, and might come to £8,000 per mile, on which the interest at 3½ per cent. would

amount to £280 per mile per annum. The total increase in the expenses would thus be £640 per mile per annum.

The passenger receipts for 1900 for the Great Northern Railway, to take a definite case, averaged 43 pence per train-mile, at which figure the receipts on a line running 8 trains each way per day would amount to £1,050 per mile per annum: the average for the whole of the Great Northern Railway being £2,460. Hence, to make up for the increased cost of the electric service the passenger traffic on such a line would have to increase 61 per cent., if the fares were unaltered. With halfpenny fares the traffic would have to be trebled.

It seems clear that, whether in England or in Italy, the full advantages of electrical traction cannot be obtained without an increase in the total running expenses, and this increase can only be met by a corresponding increase in the passenger traffic, so that the change from steam to electricity should not be made unless the increase in traffic may be reasonably expected at least to cover the increased cost of running and the interest on the capital expenditure.

Most railway managers would probably admit that the use of electricity on existing railways is worthy of consideration, and some will even go so far as to say, "If you can show that we should reduce our expenses by adopting electricity, we would do so." It is not, however, by reducing expenses that electricity is going to help the railways, but in enabling them to offer greatly increased travelling facilities to the public at a figure impossible with steam traction, and thus to meet the growing competition of the tramways.

In answer to the question as to why the Italian railway companies are adopting electrical traction, it is often urged that they are doing so because of the saving effected by the use of water-power in place of coal. This is, however, very far from being the case, since even with water-power the expenses cannot be met unless the traffic increases. The use of water-power simply reduces the increase required to pay, the reduction in the case of the Italian lines being 20 per cent. The prospects of success in England with cheap coal are more favourable than they are in Italy with water-power, as is shown by the fact that the increase in

the traffic required to pay expenses is less in England than in Italy.

The figures given above do not take any account of the relative possibilities of travel development in the two countries. Milan has a population of 471,000, about equal to that of Birmingham, but the towns along the line now being electrified are all quite small, Gallarate having a population of 8,000, Varese of 6,000, and Arona of 4,000, the largest being Busto Arsizio with 13,000. Taking the different lines radiating from Birmingham, by way of comparison, we find that the united populations of the two largest towns on each line within a radius of 45 miles amount to 39, 41, 63, 86, 101, 109, 121, and 185 thousand. With these figures before one, it is difficult to avoid the conclusion that the possible increase in travel is far greater in England than in Italy, and that if there is a field of usefulness for electrical traction on Italian steam railways, there is a still greater field of usefulness on the railways of our own country.

I wish to express my thanks to the officials of the Strade Ferrate del Mediterraneo, and of the Strade Ferrate Meridionali, and in particular to Signor Ing. Victor Tremontani, Signor Ing. Pietro Lanino, and Signor Ing. Leone Olper for their kind assistance in furnishing me with data and information. I am also indebted to Signor Tremontani for the views and plans in Figures 3, 5, and 6, and to Messrs. Ganz & Co. for the view in Figure 2. In preparing the maps and profiles the following have been consulted: The map of Italian railways published by the Instituto Geograpico Militare, and the official train sheets of the Adriatica Railway Company.

The President.

The PRESIDENT: We are all very much indebted to Professor Carus-Wilson for this admirable paper, which, having regard to the proposed visit of the members of this Institution to Italy next spring, has come at a most opportune time. I have read Professor Carus-Wilson's paper with much interest, and I think that he has done the railway companies of the kingdom a service in dealing with the question, as he has, largely from a commercial point of view. It is simply this aspect that will affect the railways of this kingdom; for they are commercial institutions, and their object of course is to earn a fair dividend for their shareholders. If it can be shown that by the adoption of electrical power advantage is to be obtained either by economising the expenses or increasing the number or the value of the fares, the

railway companies will be equally anxious with the electrical engineer to adopt electricity. But I am afraid that many people in reading Professor Carus-Wilson's paper may feel inclined to doubt whether such will be the case, because he comes to the conclusion that railway companies have to look, not to economies, so much as to increase of passengers and increased facilities. I am not in harmony with the author in his deductions, because it appears to me both from the figures which he has shown on the screen, and from the figures which he has been good enough to produce, and which I accept as quite reliable, that there is no comparison between the Italian railways to which he has referred and British railways. British railways are much more costly than railways in most other European countries, because the work is carried out in a much more complete and, consequently, more expensive manner. British railway companies have a much larger traffic, and our lines are more full of trains than are those which have been referred to in the paper. I think if we could only make a more thorough comparison between the expenses that have to be met on the Italian railways and those which have to be incurred by British railways, we should, unless I am mistaken, see that the comparison did not quite support the conclusion. I am very glad to note that the Italian administration are dealing with this question, not in the sense it has often been suggested it should be dealt with by British railways, that is by an enormous increase of speed. They are increasing their speeds, but they are not adopting an extravagant speed. It appears to me that it would be far better for railways to consider this question based upon a moderate speed rather than attempt a very high speed, which means the employment of much higher power, and consequent cost. The President.

I feel quite sure that if increased facilities would increase the traffic on the lines to which Professor Carus-Wilson has referred, the like increased facilities on British railways ought to be attended with far better consequences.

Mr. CHARLES STEEL: I came here to listen, not to speak; to learn, and not to teach. I have followed the remarks of Prof. Carus-Wilson with very great care, but I confess that I am bound almost to endorse the chairman's remarks in preference to the observations of the author. I will give my reasons. Mr. Steel.

The conditions of railway working in Italy and the character of the traffic are widely different from what they are in this country. The introduction of electricity upon a railway upon which there are run trains consisting of few vehicles can only be accomplished—that is if that introduction is to be accompanied by a large increase of traffic—where there is a huge population to work upon. If you take the two points, Milan and one of the country places to which Professor Wilson has referred, you have not a large traffic. You have at one end a large town—Milan, and you have the country town at the other end; but it does not follow that, because you have a frequent service between these two places, you are necessarily going to increase your traffic. When people travel they usually have an object in travelling, and people are not going to travel between Milan and the country places

Mr. Steel. merely because there is a frequent train service if they do not wish to travel for any other reason. It does not follow as a matter of course that, because you have there a quick service, you will create traffic. The case of London is altogether different; but even in respect of the London traffic I shall have to point out a fallacy which I think pervades the table No. 7, to which Professor Carus-Wilson drew our attention. I shall be very glad indeed if he can remove the impression which the table created in my mind. He showed the expense of running eight trains as compared with that of running twenty-eight trains. The number of trains was three and a half times as many when worked by electricity as when worked by steam. The expenses, I think, were £320 in the case of steam, and £960 in the case of the twenty-eight electric trains. The eight trains consisted, we will say, of seven vehicles each, or fifty-six vehicles in all. The twenty-eight trains consisted of two vehicles each—fifty-six again. But the expenses are three times as much in the case of the twenty-eight trains with fifty-six vehicles as they are of the eight trains with fifty-six vehicles. Therefore you are increasing your expenses enormously and are not increasing your traffic capacity.

That brings me back to the point to which I referred in respect of the character of the traffic, and which must be considered in dealing with this electric train question. In the case of suburban traffic it is heavy in the morning and in the evening, though not quite so heavy at night as in the morning, as it then extends over a longer period, but during the day-time it is not so heavy. At any time of the day, however, trains of two vehicles are not adapted for dealing with London suburban railway traffic.

Then, again, there is another difficulty to which Professor Carus-Wilson has not alluded in respect of the introduction of electricity into this country. You cannot run trains at short intervals over crowded lines. Take the case of the railway to which you have alluded, and with which I am thoroughly acquainted. You could not run a five minutes' service over the main line of the Great Northern Railway. What would become of your ordinary or general traffic if you did? That is one of the great difficulties with which the existing railways of this country will have to contend in respect of this particular question. Again, you cannot reduce the expenses as they do in Italy. We have had shown to us a photograph of a so-called railway station in Italy; but the Board of Trade in this country would not allow for one moment a station of that kind to be used, and the Board of Trade will continue to exercise its power, for the public have demanded that there shall be still closer supervision exercised over the railways of this country. That supervision is not altogether an unmixed blessing. You cannot dispense with your signalmen. Your block-system will have to be continued, and, whenever you come to deal with electricity in respect of railways, you will also have to consider in connection with it what effect it will have upon your block-system. My own feeling is that, so far as the ordinary railways of this country are concerned, there is not much hope of electrification. I think certainly not in the suburbs of London, and it is there where, if they could be at all adopted, they

should be introduced. My view is—and I think it has been confirmed by the paper to-night—that, if electrical railways have to deal with passenger traffic in this country, they must be electrical railways for that traffic only, and for no other. To introduce electricity on existing railways there would have to be provided additional lines, and the cost in the neighbourhood of London of providing these for this particular traffic would be simply prohibitive. The price of land in the neighbourhood of London has gone up to an enormous extent. Land that cost £20,000 twenty years ago could not to-day be purchased for £100,000. And it must also be borne in mind that in providing additional lines for suburban traffic to be worked electrically it would not relieve the companies of the cost of working and maintaining the existing ones. Mr. Steel.

I am sure of this—that railway chairmen and directors would be very slow at this time of day to introduce any system which would increase the working expenses, and which would leave the question of obtaining increased traffic a problem to be solved in the future.

I am satisfied also that there is a need for electrical lines in this country, and I believe that the problem of overcrowding in London will be mainly solved by this means.

Mr. H. M. SAYERS: I think that Mr. Steel has afforded us one of the reasons why England is behind Italy in electrifying main railways. Except for a pious hope in the last few words, Mr. Steel's interesting speech has been a series of *non possumus*, from which it appears that the main lines of this country cannot do anything in the way of electrification, or in the way of relieving the overcrowding difficulty, or in the way of giving us better service generally. And therefore I suppose that Mr. Steel is content to be left to his coal or mineral traffic, because it seems to me that that is what it will come to. Mr. Sayers.

To come to the paper, Professor Carus-Wilson has earned the gratitude of all engineers, especially all electrical engineers, by taking a live example and dissecting it in this very careful way with an eye to the commercial elements. These commercial elements are the first elements, of course, to be considered. We have been treated during the last few months to a very interesting series of papers showing how various electrical engineers would electrify railways if they had the chance. It is refreshing to know that so many people are willing to try their hands at a very difficult problem. But before they can get a chance they have got to show gentlemen like Mr. Steel and Mr. Steel's directors that it will pay; and they have undoubtedly got a very hard problem before them in the way of inducing such a conviction.

But I would like to point out that we have got an example nearer home showing how the increase of facilities does increase traffic. Within the last five years a good many tramways have been converted from animal- and steam-traction to electrical traction; and in a good many cases tramways have been altered from lines of a few miles in length, within the limits of towns, to tramways running well outside the towns, and linking up large towns and small towns. One example with which I am acquainted carried in its palmiest days of steam traction about 1,800,000 passengers per annum. In its first (incom-

Mr. Sayers. plete) year of electrical traction, over a slightly increased length of line, it carried six million passengers. What was the difference in the character of the service? Exactly the difference that Mr. Wilson has shown us between the character of steam-service and the character of electrical-service on the Italian lines—a much more frequent service of cars, a higher speed, lower fares, and a smaller carrying capacity per car. It is a very curious thing that tramway statistics show that the earning capacity of any car all the way from twenty-eight passengers to sixty-three passengers is almost fixed. From eightpence to twelvepence a mile is what a car earns, and it does not very much matter what its capacity is. That means, of course, that you should run as many cars as you can so long as the receipts leave some minimum balance over the running expenses, and that with a frequent service a comparatively small margin over the running expenses will cover the fixed charges. Now that is where electricity will help the English main lines when it is adopted. The trouble in English main lines is the enormous capital expenditure that has been incurred in constructing them. They work at somewhere between 50 and 65 per cent. of their earnings. Of the balance I suppose four-fifths goes in the debenture interest or its equivalent. At all events, the balance that is left the ordinary shareholders, we know, is somewhere in the neighbourhood of 4 or 5 per cent. It is perfectly clear that even quite a small increase in the traffic, if it is not accompanied by a disproportionate increase in the working expenses, will increase the dividend, besides paying the cost on the electrification capital.

I had occasion last year to consider a particular case of two large towns in this country connected by competing lines. It was a revelation to me at the time to find what a very small passenger revenue those lines had, and it was also very curious to find that if one of those lines were electrified and used for passenger traffic, it would be capable of carrying about four times as many people as now use the three lines, it would leave the other lines available for the goods traffic, and it would certainly pay a very big dividend on the cost of electrification. I believe that to be the case generally.

Mr. Steel says that people travel for a purpose. Well, they do, but there is some proportion between the purpose that will make a man travel and the trouble and cost of the travelling and the time that it takes to travel. I have to travel a good deal as a matter of business, and I travel as little as I can, but I should travel a good deal more if railway travelling were not only cheaper but more expeditious, and if it were not such a nuisance to get across, say, from Mr. Steel's line to the Lancashire and Yorkshire main line. The cause of the nuisance is that the time tables are arranged with entire disregard to the meeting of trains between different companies' lines, and because the services of many of the cross-country lines give intervals of from two and a half to four and a half hours between the trains, which are all slow. And that means an enormous expenditure of time which can ill be spared by a busy man. When it comes to travelling for pleasure, people choose lines and places to which they can get cheaply and quickly without much changing and waiting. If one going to a London

terminus could be sure to get taken to any town on a particular railway without waiting more than half an hour, many more people would travel for pleasure, and many more would travel because the expenditure of time and money required would be much smaller and lighter than it is now, and therefore a slighter purpose would suffice to induce them to travel. Mr. Sayers.

Mr. W. R. Cooper: I am rather uncertain whether the author wishes to apply his comparisons in this country to suburban or main lines. If to the former, then I think it will be admitted that his conclusions do not hold good, because there is generally a large amount of passenger traffic on such lines, and electrical methods lead to easier manipulation of the service. There may, therefore, be economy apart from the possibility of being able to increase the carrying capacity of such a line. With regard to main lines, it may be well to define this term by saying that the popular idea of a main line is one which is long, as compared with a suburban line, and which deals with a large amount of traffic. Branch lines with little traffic form a different class. Mr. Cooper.

It appears to me that the author's conclusion that "the full advantages of electrical traction cannot be obtained without an increase in the total running expenses, and that this increase can only be met by a corresponding increase in the passenger traffic," can be applied only to these branch lines. On such lines a good result cannot be expected unless there is a certain density of traffic. The author shows a reduction in running costs per train-mile, but as the traffic is small, an increase in the number of passengers is necessary to pay a dividend on the extra outlay.

But with main lines the case is different. Many of these are carrying as much traffic as they can conveniently handle, and although their capacity might be increased to some extent by a change to electrical methods, yet this increase would not be nearly so great as on a suburban line, partly because the character of the service is much more varied and partly because the speeds cannot be raised so very much beyond those at present in use unless alterations are made in the permanent way. Therefore in the case of main lines it is desirable to know what reduction in running costs is possible when operating a service somewhat similar to that which is worked by steam. For such lines I think the author's conclusions do not hold good.

Italian railways cannot very well be compared with railways in this country. In Italy, trains generally stop at every station, and stop a considerable time; between stations they run at a low speed, so that travelling is very slow. Thus competition by means of tramways is much easier than it is over here.

Generally consideration is given to the question of passenger traffic exclusively, but it is likely that, in the case of main lines, the goods and mineral traffic are worth greater consideration than the former, for the present conditions of working this traffic are not economical and passenger train-mileage is only about one-third or less of the whole. The uneconomical working is due to a large extent to the shunting required for goods trains. Mr. S. W. Johnson, in an address to the Institution of Mechanical Engineers (April, 1898), has stated that the

Mr. Cooper. mileage of engines in shunting or equivalent work on the Midland Railway is, for passenger trains, 13·07 per cent. of the train-mileage in addition, but for goods and mineral trains 38·73 per cent. In the same paper the cost of locomotive power in 1892 is given as follows:—

Passenger trains	...	6·94 pence per train-mile.
Goods „	...	9·29 „ „ „ „
Mineral „	...	11·68 „ „ „ „

From other figures in the same paper the following coal consumption is found:—

Passenger trains	...	36 lbs. per train-mile.
Goods „	...	53 „ „ „ „
Mineral „	...	62 „ „ „ „

In a paper read by Mr. W. E. Langdon before this Institution (Vol. 30, p. 124, 1900), it is shown that the average horse-power required is greatest for passenger trains and least for mineral. It therefore follows that the average amount of coal required per I.H.P. hour for these three classes of trains differs even more widely than the coal per train-mile. It thus appears that the greatest economy will be gained by applying electric traction to goods and mineral, rather than passenger, traffic on main lines, for the inefficient working of engines for shunting would be avoided. Of course there is the complication of sidings, but I think that this difficulty has very possibly been exaggerated.

Referring to Table VI., electric traction might mean some reduction in wages on the locomotive, but it is not likely that a single motor-man would be permitted in this country. In calculating Table VII., interest has been taken at 3½ per cent., which seems rather low.

Mr. Lupton. Mr. ARNOLD LUPTON: With regard to the exceedingly valuable paper to which it has been our privilege to listen, I am in the position of being able to agree to a great extent with the author of the paper, and also with the exceedingly valuable remarks of Mr. Steele, which appear to contradict it to some extent, but not, I think, really.

As far as I have observed, I do not know any engineer who has really grappled with all the problems which have to be dealt with in dealing with the main line traffic of such a company as the Great Northern or any other of our great main lines by electrification. But when we come to deal with branch railways where trains run comparably to those Italian railways, only seven trains a day, there the same class of circumstances would seem to involve the same treatment. You would decrease the length of the trains and increase their number, and no doubt you would increase the traffic.

There is not the slightest doubt that in the country districts of England, owing to the small number of trains running, the passenger traffic is greatly reduced and people do not travel. They telegraph, telephone, drive, walk, or cycle, when they would go by train if there were anything like a convenient service, which there is not. In some few provincial districts of England, like the busy parts of the West Riding of Yorkshire and of Lancashire, there is something like a train

service. But go a few miles away, say into Derbyshire and Nottinghamshire, and it is a whole day's work to go to the county town twenty miles off and back again. I am speaking from practical experience. But I think that very likely what Mr. Steel has said is in the main right, that there should be separate electrical railways some of these days. Mr. Lupton.

But I should like to refer to one or two details in Prof. Carus-Wilson's exceedingly valuable and carefully constructed tables, if I may so say. In Table 6, giving a comparison of English steam railways and electric railways, I take it that in the electric lines there is a vast deal more horse-power developed at the generating station than there would be in steam locomotives for an equal train service, but by more economical engines; and a cheaper kind of fuel for generating power. I venture to think that perhaps the economy of fuel in favour of electricity will be greater than that stated by Professor Carus-Wilson, because there he is dealing with the train half the length. But he has made it more than half. I think if you consider the great difference in cost of fuel—and that probably before long gas engines will be used for developing electricity, which will bring down the amount of fuel to perhaps ¾ of a pound per indicated horse-power—I think the reduction per mile will be more. Then, again, with regard to the item "Water, oil, etc.," I hardly think that it would be 0·45 if it was 0·77 in a train twice as long. But there is another item. I have read the paper through, but so far as I gather there is an additional remark which the author has not added, but which perhaps he has in his mind. In comparing the cost of steam railways and electrical railways in England and in Italy, he has added a considerable item for the interest on the cost of the electrification of the railway. Well, no doubt he is talking of existing railways. Of course in a new railway there would be interest on the cost of the steam as the alternative to interest on the cost of electricity.

Major-General C. E. WEBBER: This subject which has been brought before us, and which occupied not long ago four evenings at the parent institution, requires, I believe, far more time for discussion than it is possible to give it to-night. I am sure that if this paper can be discussed at the commencement of our next session, we shall by that time have it in the minds of a large number of practical men. We shall occupy ourselves, in a less speculative way than was the case on those four evenings, with a subject which is of so much interest. No one can read Professor Carus-Wilson's paper without meeting almost on every page questions to which they would like a reply. Any one of the author's tables requires, I think, that questions should be put as to the incidence of the figures of passenger mileage, and so on, all of which questions are largely affected by the condition of railway traffic in the various countries of Europe. Major-Gen. Webber.

Having had to prepare the article for the "Encyclopedia Britannica" which deals with "light railways" in all parts of the world, it has occurred to me that there are questions arising out of those conditions—local, climatic, cost, etc.—which vary so much as to require that such a set of tables as has been brought before us by Professor Carus-Wilson should

Major-Gen. Webber.

be subjected to the light of the experiences that are obtainable, as regards not only the very costly lines that we have in the British Islands, but also the lines where they are less costly and are built to suit the ways and the habits of peoples, which differ with those of this country.

Therefore I hope that this meeting will agree in asking you to adjourn this discussion to the first evening of our next session. I am pretty sure that in the meantime our members who will have thought over this subject will be able to give us one or two more interesting and certainly more instructive evenings than those to which I have referred. It will afford Professor Carus-Wilson not only time to consider the points which have been raised by Mr. Steel and other speakers, but also perhaps to bring before us other matter equally interesting in support of the views that he has already expressed.

Mr. Digby.

Mr. W. P. DIGBY (*communicated*): I can only read Professor Carus-Wilson's admirable and lucid paper with regret that so little in these directions is being done in England while sister countries are doing so much. I am interested to see that these lines have their passenger traffic driven by a passenger-carrying locomotive, so that, apart from these locomotives, the passenger coaches referred to as trailers are entirely interchangeable. Therefore, if in the future the Adriatica Railway Company remodelled their entire system for three-phase work while the Mediterranean Company remodelled for a continuous-current system, this absence of standardisation would only entail expense for a change of locomotive or a shunting of coaches at different breaks of system. It is much to be regretted that the rival systems are not being tried under circumstances best qualified to determine their relative advantages. The boldness and energy which characterise the action of the directors of these railways—railways which feed comparatively sparse populations—is beyond praise. Whether the resultant extra traffic required to justify their action is obtainable remains to be seen.

I would suggest that in the computation of railway statistics there is room for a new factor of comparison, namely, that of the passengers carried per mile of track per annum per million population in the districts served, inclusive and exclusive of season ticket-holders. It is possible that our President, Mr. Langdon, could obtain these figures from the different companies.

The President.

The PRESIDENT: I think that it would be unfair to Professor Carus-Wilson if we carried over the paper in the ordinary sense until next session, because he would naturally like to have the paper brought out, and we ourselves would also like to have the observations of the several speakers put into print for the purpose of circulation. But I think that we may meet the question, or the suggestion which has been made, by asking the author to reply to the discussion that has proceeded so far, and to supplement the paper by some further information which no doubt he will have gathered between this and next November, and then give us the additional remarks as a supplement to this paper.

Prof. Carus Wilson.

Prof. CARUS-WILSON: I hope that you will understand that my own wishes in this matter of postponing the discussion on the paper are

Prof. Carus-Wilson.

quite subservient to the wishes of the Institution. I really do not very much care what is done. For my own part I would perhaps prefer that the paper should be printed, but still I am quite prepared to agree to whatever the Institution thinks best in the matter.

Major-Gen. Webber.

Major-General WEBBER: May I say that I did not suggest that the proceedings of the present evening should not be printed and circulated. I rather suggested that it was essential to a further discussion that they should be.

Prof. Carus-Wilson.

Prof. CARUS-WILSON: The remarks that you, sir, were kind enough to make in opening this discussion impressed on my mind once more what I have felt in all discussions on this question which we have had here and elsewhere, namely, the great difficulty of defining one's position. One takes up a certain line and uses certain terms, and then with the very best intentions other speakers fail to enter into one's own position and make remarks which may be perfectly correct and true, but do not affect the question intended to be brought forward. A good instance of this is the meaning to be attached to the expression "main line." In several of the remarks that have been made to-night the question comes up again and again, What do we mean by "main lines"? When I showed on the screen a photograph of the official map of the Italian railways, some people supposed that I was going to read a paper on the electrification of main lines, and jumped to the conclusion that I was advocating the introduction forthwith of electricity on to the Great Northern Railway from London to York, for instance. Nothing was farther from my intention. The railways that this paper deals with are railways that may be defined as having about eight trains each way per day. I do not think that any one can say that such a railway was a main line.

Now, sir, I think that this definition offers a reply to the criticisms which you made when you said that you did not think that the figures in the paper offered a fair comparison between the state of affairs in Italy and those in this country. We have to compare a line such as is now being electrified in Italy with a line carrying the same amount of traffic in this country; and if that is done we shall have as fair a basis of comparison as is possible, and a large proportion of the mileage on our lines is comparable with that of the line from Milan to Varese, a considerable proportion consisting of lines where there are not more than eight trains a day.

The remarks that Mr. Steel made come with great weight from one who has so long carried on the responsible work of managing one of our greatest railways, and we are indebted to him for coming here to-night and giving us his views on this subject. Mr. Steel has put clearly his reasons for dissenting from the view expressed in the paper that the introduction of electricity on lines other than urban and suburban lines depends entirely upon the increase of traffic that may be expected. I still maintain emphatically that position, and am glad that Mr. Steel has made his remarks so pointed, because they give me an opportunity of again stating my belief that it is only the possibility of developing traffic that will lead to electricity being introduced upon lines such as these here considered.

Prof. Carus-Wilson.

In stating that the traffic capacity is not increased, Mr. Steel has overlooked the fact that the increase of speed gives a proportionate increase in the traffic capacity for equal accommodation. This is one of the most valuable features of the electric system.

Mr. Cooper said that it was not fair to consider only the case in which the train service was increased, that if you increase the train service of course you increase the cost of working, and that you should include also the case where the train service was not increased, but was left unaltered and the motive power simply made electricity instead of steam. Here again Mr. Cooper has struck the fundamental point of difference between the two ways of looking at this whole question. The substitution of electricity for steam simply with the object of saving coal does not offer a sufficiently substantial inducement to incur the capital cost involved.

Mr. Lupton thought that I had made the cost of the fuel too high; I hope it may be too high. I have endeavoured to be conservative in the statements that I have made. I have not gone into the question of electrifying a line constructed *de novo*, I have simply taken the case of the electrification of an existing steam line.

I would like to refer to a portion of the paper that I have not dealt with at length, that, namely, on the last page, as it answers some of the criticisms that have been made to-night. I endeavoured to find out what was the possibility of an increase of traffic on the Varese line, and when I saw the populations of the towns on this line and compared them with those on our own lines, I could not doubt that the possibility of the increase of traffic is far greater in our own country than it is on the lines that have been electrified in Italy. The railway companies in Italy have not approached this question of the increase of traffic in a policy of blind faith, as Mr. Steel suggested, merely trusting that the traffic would increase. Nothing would have been more fatuous. For years past they have been studying most carefully the connection that exists on their lines between increased facilities and increased traffic. That is the secret of what they are doing now. The electrification of these lines is the outcome of a careful and prolonged investigation of this question; and I think that the managers of our great lines should follow their example. I do not suggest that they should forthwith go and equip this line and that electrically, but that they should lose no time in taking steps to investigate the vital question of the connection between increased facilities and increased traffic, and when they have done that I think they will be more hopeful as to the travelling potentialities of the British public.

The President.

The PRESIDENT: Gentlemen, I may perhaps point out, in reference to my remarks in drawing a comparison between Italian and British railways, that I was induced to regard the reference to British railways as applicable to our large lines because the author had taken his comparison of figures from the Great Northern Railway.

I will ask you to accord to Professor Carus-Wilson a very hearty vote of thanks for his paper; and we hope that he will supplement it by further information in the early portion of next session.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :— The President.

Associate Members.

George Aldridge. | Walter Frederick Long.
Walter Hudson. | John Digby Pember.

Associates.

Arnold Dickinson Manlove. | Bernard Sankey.
Antolin Ruiz. | Edward Thornton.
Charles Jebb Vaughan.

Students.

Digby Connolly Haylock Bell. | Carl Petersen.
Percy Richards.

NEWCASTLE LOCAL SECTION.

SOME NOTES ON THE INFLUENCE OF THE SUB-STATION EQUIPMENT AND TRANSMISSION LINE ON THE COST OF ELECTRICITY SUPPLY.

By ANDREW STEWART, Associate.

(Paper read at the Meeting of January 27th, and discussed February 3rd, 1902.)

In the natural process of evolution through which all things are passing, changes, often of the most radical nature, take place in a comparatively short space of time, so rapidly, indeed, that it is only by a survey of all that has occurred over three or four years that their importance is fully realised. One of the most striking changes has been the growth of electricity supply. Not so very long ago the narrow limits of a small town practically defined the area over which electricity supply was deemed advisable or economical. To-day such limitations no longer hold good, and a whole county is deemed none too large for the operation of one supply authority. With the extension of the area of supply have come new problems of a different nature to those already solved. Direct current is still the proper thing to distribute to consumers, but transmission over long distances postulates high pressures, and high pressures mean alternate currents—generally two- or three-phase. The transformation of high-pressure alternate currents to low-pressure direct current involves apparatus of a nature not yet well defined. Opinions seem to differ as to whether rotatory converters, synchronous, or asynchronous motor-generators should be used. Sometimes the former is used, to the exclusion of the two latter; in other cases, one or other of the two last-named types is employed; while in some instances the two latter are employed together, generally asynchronous for the smaller and synchronous for the larger machines. The transmission and transformation of electrical energy under the

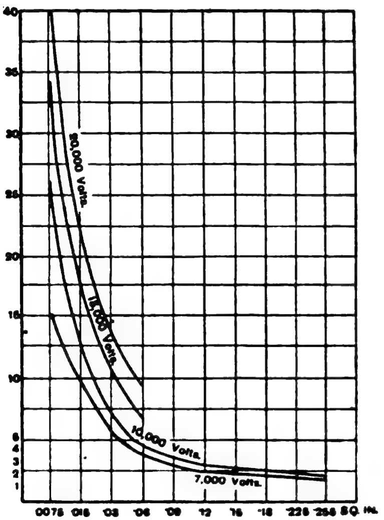


FIG. 1.

conditions existing on a distribution system of the nature already defined is accompanied by losses, and involves annual charges for interest and depreciation which will bear investigation, producing, it is hoped, results of considerable value. What, however, is still more important, by inducing others to discuss the subject, the diversity of opinion existing will assume concrete shape, and a more definite idea of the various considerations, both financial and engineering, will be the result.

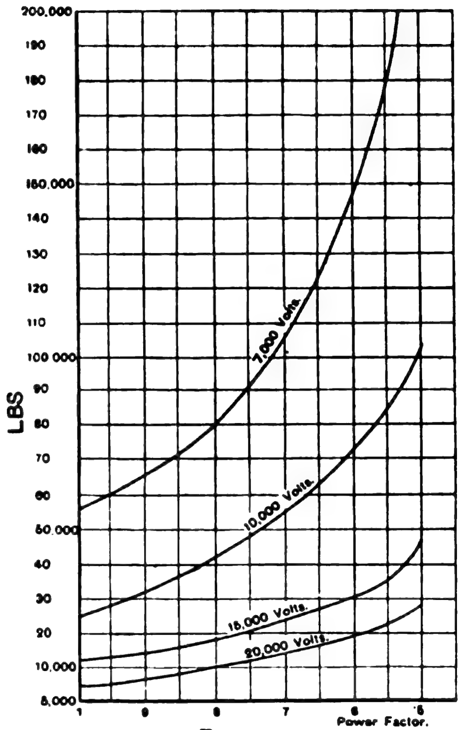


FIG. 2.

Starting with the transmission line, if any diversity of opinion does exist, thanks, perhaps, to an autocratic Board of Trade, it finds but little chance of expression. The manner in which the mains are laid being specified, a limit is placed on the amount of energy which may be transmitted by one cable; and overhead wires are, practically speaking, out of the question for the same reason. Within these limits one may exercise ingenuity in bringing the cost of laying mains on the prescribed scale to an irreducible minimum, but beyond that the Board of Trade draw the line. There are, however, some features which demand attention in relation to the cables, the cost of copper insulation, and the material necessary to preserve the integrity of the latter, or to give it mechanical protection. These are, of course, points which principally concern the cable manufacturer, but are, nevertheless, of great importance to the electrical engineer, who has to consider the question from its dividend-earning aspect. Fig. 1 gives some curves plotted from the cost of high-tension paper-insulated, lead-covered and armoured cables, showing the relative cost of copper and insulation at various E.M.F.'s. (The abscissæ represent the size of the cable, and the ordinates a value obtained by dividing the cost of insulation by the value of the copper in the cable.) The most remarkable feature is the very great cost of insulation at high voltages. With small cables, the cost of insulation becomes a serious matter; its cost, in fact, varies in proportion to the E.M.F., suggesting at once the proposition that if the copper varies inversely as the square

of the E.M.F., while the insulation varies more or less in direct proportion to the E.M.F., there must be a point at which copper will cost so little and insulation so much that it will pay to work with a lower E.M.F. This point will depend upon the relative price of copper and insulation.

Fig. 2 shows the approximate weight of copper required to transmit 1,000 k.w. 10 miles with 10 per cent. loss at full load at E.M.F.'s of 7,000, 10,000, 15,000, and 20,000 volts between the three-phase lines, at power factors varying from units to ·5. It should be noted in passing that the curves are plotted for the same percentage loss in watts, and not for the same percentage drop in volts; were the latter taken instead of the former, the curves would be much flatter at low-power factors. The influence of a high-power factor on the cost of copper is too obvious to require any comment. I have taken 90 per cent. as the efficiency of transmission at full load, chiefly because opinions differ as to whether or not a fairly high efficiency of transmission should be taken. It is, as is well known, a commercial question depending upon how many hours per day the maximum load will last.

Fig. 3 shows the cost of copper, insulation, and total cost of three-core cable to transmit 1,000 k.w. at 7, 10, 15, and 20 thousand volts over a distance of 10 miles with 10 per cent. loss in watts at full load. The large cost of insulation on such a line is very apparent, as also is the fact that the economic voltage is a definite one in this particular case. Beyond 15,000 volts, the line becomes more costly, and this is also the case at less than 15,000 volts; a line for a power-factor of ·9 shows the same configuration. The section at the lower power-factor is worked out for the same percentage loss in watts; the cable is, therefore, larger and more costly. The power-factor indicated is what may be expected if large induction motors are employed. The value ·9 will only be obtained, however, if the wave-form of motor and generator are alike, and this has been assumed throughout. If they are not alike, one may expect a power-factor not of ·9, but of much less. These observations also apply to synchronous apparatus. No amount of juggling with the exciting current of a synchronous motor will make the power-factor unity if the wave-forms are dissimilar. Carried much further, these curves assume a U shape; on one side copper predominates, on the other insulation.

Taking two cables of approximately half the section and plotting copper and insulation as before, it will be seen (Fig. 4) that pretty much the same contour is obtained, but the influence of the predominant factor—viz., insulation—is still more marked, and the engineer who declines to rely on one cable must pay a heavy price in insulation for his additional safety. Of course, in most cases with a fairly long line, it will be better to run a cable from the nearest sub-station if there are others in the vicinity, as, for instance, with two sub-stations, A and B. From the generating station to A, and also to B, with a cable linking up A and B, either sub-station may be fed direct from the generating station, or A may be fed *via* B, or B *via* A. Nevertheless, were a sub-station located 10 miles distant, and no

other in proximity to it, it is to be doubted if any engineer would rely on a single three-core cable, no matter how carefully laid.

The important point which is brought out prominently by these curves is that while the cost of copper varies inversely as the square of the E.M.F., the insulation follows a law quite the reverse, though perhaps not so definite; also that with underground cables and the cheapest of all known reliable insulators one cannot take full advantage of extra high pressures, and on a large system the money sunk in insulation may reach a formidable figure. It is also apparent from

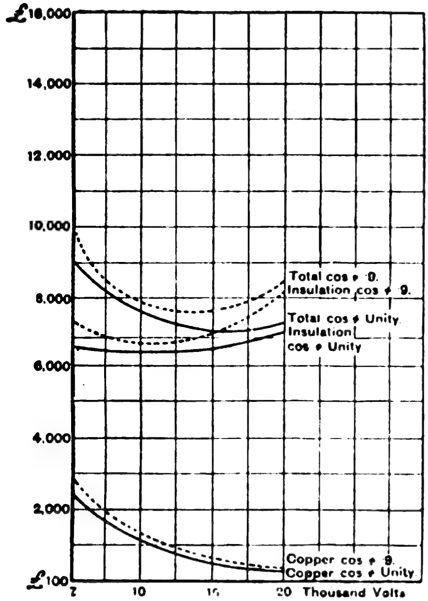


FIG. 3.

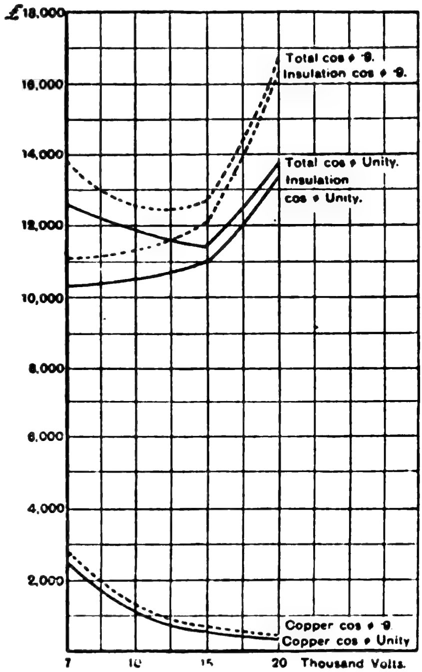


FIG. 4.

Fig. 4 that 7,000, 10,000, and 15,000 volts are all more economical than 20,000 volts, which goes to prove that under existing regulations long-distance power distribution will develop along lines entirely different from American or even Continental practice. From these curves we may conclude at once that there is a definite voltage at which, with any given set of circumstances, maximum economy is secured, and that voltage will depend upon the size of the cable, it being obvious that if the power to be transmitted reaches several thousand kilowatts, so that cable of comparatively large section has to be employed, a higher voltage becomes commercially possible, because, as is seen from Fig. 1, with large sections

insulation costs are not abnormal in their relation to the cost of copper. It may be pointed out in passing that the prices which the writer has been able to obtain do not always agree, especially with cables of large section; in some cases the insulation costs more than is shown in the diagram. The difference is not, however, very great, and in the cables of smaller sections there is a remarkable agreement between British and Continental prices, so that such conclusions as may be drawn are applicable over a fairly wide range.

The Sub-Station.

The sub-station equipment has been so fully discussed by several members of this Institution that I will not make any lengthy observations upon it. Nevertheless, one or two engineering points will be raised in order that their influence upon any conclusions at which we may arrive shall not escape observation. The simplest sub-station is undoubtedly one equipped with asynchronous motors driving one or more direct-current dynamos. The station plant and switch gear are about as simple as one could wish. The pressure on the direct-current side is entirely independent of the alternate-current side, and capable of considerable variation, hence a mixed lighting, power, and traction load can be easily served. The asynchronous motor possesses most of the characteristics of a shunt-wound direct-current motor, and is thus unlikely to disturb anything else on the system, whilst sudden overloads, such as shorts, have no disorganising effect upon several induction motors in parallel. Such machines may be built to take the line pressure on the stator, consequently saving the cost of, and losses in, step-down transformers. Variations in the line voltage do not influence them, except to limit their overload capacity, while no direct current-excitation is required. On the other hand, they have a power factor less than unity, which involves either additional capital outlay in copper or increased line loss, while their power factor drops with overloads, hence limits their overload capacity when most wanted by lowering the impressed E.M.F. Sub-stations so equipped are economical in point of attendance, no synchronising being necessary —indeed, they may be started with the ease of a shunt-wound direct-current motor, either by an auto-transformer or a resistance in the rotor, the latter by preference. Their ability to carry an overload, provided the impressed E.M.F. is maintained, is limited almost entirely by the capacity of the direct-current generator which they drive.

The next type of sub-station equipment is the synchronous motor-generator, which possesses most of the advantages which have already been cited as pertaining to an equipment whose direct-current side is independent of the alternate current. It has one feature possessed also by the rotatory converter, that its power factor is adjustable over a fairly wide range, and hence may be maintained at or near unity, or may be employed by reason of its condenser properties to cover the sins of some neighbouring induction apparatus, and is in some cases employed in conjunction with induction motors for this purpose. It has con-

siderable overload capacity, but this is, of course, to some extent determined by the rating of the machine. If seriously overloaded it will pull up, but, unlike an induction motor, will not generally recover when the overload has passed off. It is influenced by the cyclic irregularity of the power-house engines. Direct-current excitation is a necessity, and must be synchronised before paralleling, which postulates a more skilful type of attendant. It is as liable to hunt as is the rotatory converter, but it seems that the tendency of either type to do so has been exaggerated : certainly as far as I have been able to ascertain, it seems that, provided the cyclic irregularity of the power-house engines is kept within certain limits, other causes, such as shorts, etc., do not seriously influence its stability.

The rotatory converter is perhaps the most popular means of converting alternate to direct current ; its outstanding advantage—viz., low first cost and high efficiency—has won for it a place which otherwise, it might not have occupied. As an engineer must, if he is to justify his existence, do things for less money than any one else, he generally finds that he must modify, as far as possible, the undesirable features of the cheaper apparatus, and use it. It is not altogether remarkable, considering their characteristics, that converters have not found much favour in this country ; they are sensitive to fluctuations of the line E.M.F., and as the direct-current pressure bears a definite ratio to the impressed volts on the alternate-current side, any variation on the latter side will be reproduced on the direct-current side. Moreover, systems where the ratio $\frac{\text{mean load}}{\text{maximum load}}$ is low need not, in order to ensure a maximum economy, have as much feeder copper as one with a higher ratio, hence the rapid drop in line volts due to a sudden overload would become apparent on consumers' lamps. Another disadvantage is that, should several well-loaded rotatory converters be in parallel, and one become suddenly overloaded it would tend to cause hunting all round, as a condition of unstable equilibrium would be set up. Of course a liberally rated machine, fitted with damping coils, would modify these disadvantages considerably, but liberal rating means more capital, and, as will be shown presently, capital really has more influence on the cost of electricity supply than anything else. Nevertheless, rotatory converters are in practice more reliable than is generally supposed. Some time ago the writer carried out numerous experiments with a converter that was feeding lamps, and it was only under the most adverse conditions, sudden and heavy overloads, that the objectionable characteristics of the machine became apparent. On a large tramway system with which the writer is acquainted, the converters are run in parallel on loads of the most trying nature, yet their performance is all that can be desired.

Coming to the resultant costs per unit delivered, we must, in order to institute a comparison, have some definite figures. That these figures must be hypothetical is obvious ; indeed, not until some one designs, say, six power schemes equipped with six different systems of transmission and conversion, will any definite data be forthcoming. We can, however, by assuming certain conditions, arrive at conclusions

which may serve as a guide in determining the merits of one or other method of transmission or conversion. The generating station is assumed to cost £25 per kilowatt installed. I may point out *en passant* that the above figure is quoted merely as a basis. Some large stations have been built and equipped for this sum, but as what a station is estimated to cost, what it really has cost, and what it is likely to cost before it is ultimately finished, are all points upon which much might be said, the figure is quoted with all due reserve. Assuming that 20 per cent. of the plant is spare, the cost per kilowatt available for supply purposes will be £31·2 while a diversity factor of 1·5 has been taken making the cost per kilowatt maximum demand = £20·8.

It has been assumed in the following tables that at the end of the 10-mile line already discussed we shall place a sub-station of 1,250 k.w. capacity, consisting of two sets of 500 k.w. and one of 250 k.w. Further, the maximum load on this station should be 750 k.w.; this would allow of one 500-k.w. set being in reserve, leaving the smaller one to deal with the day load, which is probably an economical arrangement for a load factor of 30 to 40 per cent. This is admittedly a high load factor, but not greater than the sanguine promoters of the Power Bills would have us expect when these schemes are properly under way, nor greater than is obtained in tramway work. Such a sub-station might be equipped with synchronous or induction apparatus, or three- or six-phase rotatory converters. The station may even contain a combination of the first and second types; such combinations seem favoured in some quarters by reason of their flexibility. Smaller machines might be asynchronous, giving easy starting from the alternate-current side, and the larger, synchronous apparatus with its accompanying high power factor (not necessarily unity).

The capital cost would be somewhat as follows:

500-k.w. Sets.

	Motor-generators.				Rotatory converters.		
	Asynchronous.		Synchronous.		Three-phase.		Six-phase.
Total..........	£2,750	...	£2,750	...	£2,375	...	£2,125
Per kilowatt	£5 10s.	...	£5 10s.	...	£4 15s.	...	£4 5s.

Only the converters include static transformers.

250-k.w. Sets.

Total..........	£1,750	...	£1,750	...	£1,312 10s.	...	£1,250
Per kilowatt	£7	...	£7	...	£5 5s.	...	£5

The total capital outlay on such a station will therefore be: asynchronous or synchronous, £7,250; rotatory converters—three-phase £6,062, six-phase £5,505.

The efficiency is as follows:

500-k.w. Sets.

	Asynchronous. Per cent.	Synchronous. Per cent.	Rotatory converter, including statics. Per cent.
Full load	86	86·5	92
Three-quarter load	84·3	85	90·5
Half-load	81·5	81·5	88

250-k.w. Sets.

Full load	84	84·3	90
Three-quarter load	82·5	82·5	89
Half-load	78·5	78·5	85

Taking the maximum load at about 750 k.w., and a load factor of about 38 per cent., we have 2,490,000 units required at the low-tension 'bus bars. This output would be obtained with the smaller set, running with a mean load of, say, 200 k.w. over the 24 hours, and the large set with 500 k.w., about four hours per day. The smaller set would thus convert 1,760,000 units per annum and the larger about 730,000 units. The hypothetical nature of these figures should, of course, be borne in mind. With the smaller set running, as already noted, at about 80 per cent. of its load, its efficiency would be about 83 per cent., and that of the line at this very light load about 99 per cent., giving 82½ per cent., therefore to get 1,760,000 units on the low-tension side approximately 2,140,000 units must be supplied at the high-tension end. The load on the large machine being at all times added to the smaller one, the line load will, while the larger machine is running, be the sum of these two, and the line efficiency about 95 per cent., the efficiency of the machine being 84·3 per cent., a total of 80 per cent., which means 910,000 units at the high-tension end. The units at high-tension generating station 'bus bars will then be 3,050,000, and at low-tension sub-station 'bus bars 2,490,000, representing an over-all efficiency of 81·2 per cent. It should be noted that a proportion of the units supplied to the small machine will be delivered to it not at 99 per cent. line efficiency, but at 95 per cent. This, however, has been neglected, because while complicating the problem it does not give results of corresponding value. The process by which my results have been reached is in the above case fully explained, and in all other examples the results only will be quoted.

Table I.—Synchronous Motor-Generator—15,000 Line Volts, Two Three-Core Cables, one spare.

Capital Costs.

Sub-station plant	£7,250
Buildings	900
Copper in line	1,000
Insulation	13,000
Laying and reinstatement...	5,873
	£28,023

= £22·5 per kilowatt installed. = £37·5 per kilowatt of maximum demand, taking 750 k.w. as maximum demand.

Total Capital Cost per Kilowatt Demanded.

Generating station	£20·8
Line and sub-station	37·5
Total	£58·3

Annual Costs—Standing Charges per Kilowatt.

	£	s.	d.
Interest on capital at 3 per cent. (£58·3)	£1	15	0
Depreciation, 7 per cent. on £20·8, generating station	1	8	7
Depreciation, 7 per cent. on £10·8, substation plant and buildings	0	14	7
Depreciation, 5 per cent. on feeders, 1 per cent. on ducts	1	0	3
	4	18	5

Running Costs.

	£	s.	d.
Labour (one engineer and one labourer per shift) = £456 per annum, = £·61 per kilowatt maximum demand	0	12	3
Proportion of distribution engineer's salary and staff charges, say £100 per annum per sub-station = £·13 per kilowatt maximum demand ...	0	2	9
Total annual cost per kilowatt	£5	13	5

Of these charges £3 12s., or 58 per cent., is on account of mains and sub-station. Over-all efficiency = 81·2 per cent. A further 1 per cent. (nearly) is lost in dielectric hysteresis,[1] reducing this figure to 80·2 per cent. A unit costing ·3d. at high-tension station 'bus bars will cost ·373d. at low-tension 'bus bars, and a consumer using a maximum demand of 100 k.w., with a mean of 70 k.w. over 24 hours, will use about 613,200 units per annum, which at ·373d. costs £950. We thus have—

Energy costs	£950
Fixed charges	565
	£1,515

Average price per unit, ·59d.

[1] The charging current of this line (capacity 1·25 microfarads) would be at no-load about 5·8 amperes = 152 apparent kilowatts. The power factor has been taken at ·023, giving a loss of slightly over 30,000 units per annum. This loss has been considered in the paper as a function of the line loss; it really is a fixed loss, independent of the number of units transmitted, and should be reckoned at the works cost per unit, in this case about £38 per annum per cable in use, this figure being placed amongst *annual* charges. The cost of the dielectric losses may seem small, but it must be noted that there may be six to eight such cables radiating to various sub-stations all in use continuously. With smaller cables, the losses are not reduced in proportion, as the ratio of sectional area to surface does not diminish.

Consumer using 100 k.w. maximum demand and mean of 70 k.w. over 10 hours per day: 255,000 units per annum at ·373d.	£400
Fixed charges	565
	£965

Average price per unit, ·9d.

Typical short-hour consumer using 100 k.w. maximum demand, and using that 100 k.w. one hour per day: 36,500 units at ·373d.	£57
Fixed Charges	565
	£622

Average price of 4·1d. per unit.

TABLE II.—Induction Motor-Generator.—Power Factor, ·9.—15,000 Line Volts.

Capital Cost.

Sub-station plant	£7,250
Buildings	900
Copper in line	1,210
Insulation	14,000
Laying and reinstatement...	5,873
	£29,233

= £23·9 per kilowatt installed. = £39 per kilowatt maximum demand.

Total Capital Cost per Kilowatt Maximum Demand.

Generating station	£20·8
Line and sub-station	39·
Total	£59·8

Annual Costs.

	£	s.	d.
Interest on capital at 3 per cent. on £59·8	£1	16	0
Depreciation, 7 per cent. on generating station, £20·8	1	8	7
Depreciation, 7 per cent. on sub-station, plant and buildings, £10·8	0	14	7
Depreciation, 5 per cent. on feeders, 1 per cent. on ducts and manholes	1	2	0
	5	1	2
Labour at sub-station = £·61 per kilowatt maximum demand, proportion of distribution engineer's staff charges	0	15	0
Total fixed charges	£5	16	2

Of this amount £3 15s. 7d., or 67 per cent., is on mains and sub-station account. Over-all efficiency of system, 80¾ per cent. Allow an additional 1 per cent. for dielectric hysteresis, 79¾ per cent.—*i.e.*, a unit costing ·3d. at high-tension 'bus bars of generating station will cost ·387d. at low-tension 'bus bars of sub-station.

Consumer as before: 613,200 units at ·378d.	£962
Fixed charges, £5 16s. 2d. × 100 k.w.	580
	£1,542

$$\text{Average of } \frac{£1{,}542}{613{,}200} = \cdot 61\text{d. per unit.}$$

Consumer using 100 k.w. maximum demand and 70 k.w. 10 hours per day: 3,650 × 70 = 255,500 × ·378d. =	£403
Fixed charges...	580
	£983

$$\frac{£983}{255{,}500} = \cdot 92\text{d. per unit.}$$

Short-hour consumer, 100 k.w. maximum demand, and used it one hour per day: 36,500 × ·378d. =	£57	10	0
Fixed charges	580	0	0
	£637	10	0

$$\frac{£637\ 10\text{s.}}{36{,}500} = 4\cdot 2\text{d.}$$

TABLE III.—Rotatory Converter Sub-Station Equipment—15,000 Volts

Sub-station plant, including statics	£6,062
Buildings	750
Copper	1,000
Insulation	13,000
Laying and reinstatement...	5,873
	£26,685

Cost per kilowatt maximum demand (750 k.w.), £35·5.

Total Capital Cost per Kilowatt Maximum Demand.

Generating station	£20·8
Sub-station and mains	35·5
	£56·3

Annual Costs.

Interest at 3 per cent. on £56·3	£1	13	9
Depreciation at 7 per cent. on £20·8...	1	8	7
" " 7 " £9·2	0	12	8
" " 5 " feeders and 1 per cent. on ducts, etc.	1	0	4
	4	15	4
Labour at sub-station and distribution, department charges as before	0	15	0
	£5	10	4

Of this amount £3 10s., or 63 per cent., is on mains and sub-station account. Over-all efficiency = 88 per cent. (89 − 1 per cent. for dielectric loss). A unit at generating station costing ·3d. will cost ·343d. at low-tension terminals in sub-station.

Consumer as before: 613,200 units at ·343d.	£876
Fixed charges, £5 10s. 4d. × 100	550
	£1,426

$$\frac{£1{,}426}{613{,}200} = {\cdot}558\text{d. per unit.}$$

Consumer 100 k.w., maximum demand 70 k.w., 10 hours per day: 3,650 × 70 = 255,500 × ·343d.	£366
Fixed charges...	550
	£916

Average price, ·852d.

Short-hour consumer, 36,500 × ·343d. ...	=	£52	5	0
Fixed charges	=	550	0	0
		£602	5	0

Average price, 3·95d. per unit.

TABLE IV.—Synchronous Motor-Generator—Three Cables, 15.000 Line Volts (one cable spare).[1]

Sub-station equipment	£7,250
Buildings	900
Copper	750
Insulation	16,500
Laying and reinstatement	6,460
	£31,860

Cost per kilowatt installed, £25·4; ditto maximum demand, £42·3.

[1] A draw-in system in cast-iron pipes has in all cases been assumed.

Total Capital Cost per Kilowatt Maximum Demand.

Generating station	£20·8
Sub-station and mains	42·3
	£63·1

Annual Charges.

	£	s.	d.
Interest at 3 per cent. on £63·1	£1	17	10
Depreciation at 7 per cent. on £20·8	1	8	7
" 7 " £10·8...	0	14	7
" 5 " feeders and 1 per cent. on ducts, etc.	1	4	3
	5	5	3
Labour at sub-station and distribution charges ...	0	15	0
	£6	0	3

Of this sum, £4, or 66 per cent., is on mains and sub-station account. Over-all efficiency of mains and machinery remains as Table I., except that the line efficiency is somewhat higher, due to a slightly larger copper section having been taken, a cable exactly half the section of the size in Table I. not being a maker's size. The slight gain due to this has been neglected. On the other hand, the losses due to dielectric hysteresis have been more than doubled, as the condenser action of a cable is, *inter alia*, proportional to the area of conductor exposed to the insulation. This has been more than doubled. Hence, if we put 2½ per cent. to this we shall be safe. This amount would not be exceeded, as, although the loss may mean more than double that in Table I., it is unlikely that both cables would be used in parallel through the whole 24 hours. Over-all efficiency, therefore, will be 79 per cent., making a unit at ·3d. in generating station cost ·382d. at low-tension terminals.

Consumer using 70 k.w. for 24 hours, 100 k.w. maximum demand: 613,200 at ·382d.	£972
Standing charges, 100 k.w. × £6 0s. 4d.	600
	£1,572

Average cost of ·62d. per unit.

Consumer using 70 k.w. for 10 hours, with 100 k.w. maximum demand: 255,500 units	£408
Fixed charges	600
	£1,008

Average price, ·94d. per unit.

100 k.w. Maximum Demand used One Hour per Day.

Energy cost, 36,500 units at ·382d.	£58
Fixed charges	600
	£658

Average price, 4·32d. per unit.

TABLE V.—Six-Phase Rotatory Converter—15,000 Volts, fed through Bare Overhead Wires; Six Line Wires.

Capital Costs.

Sub-station plant	£5,505
Buildings	750
Cost of 10 miles overhead line with six No. 10 copper wires (two separate circuits), including erection...	3,438
	£9,693

Cost per kilowatt installed, £7·72; ditto maximum demand, £12·8.

Generating station	£20·8
Sub-station and mains	12·8
Total	£33·6

Annual Costs per Kilowatt of Maximum Demand.

	£	s.	d.
Interest at 3 per cent. on total capital per kilowatt...	£1	0	0
Depreciation, 7 per cent. on generating station, £20·8	1	8	7
Depreciation, 7 per cent. on sub-station and buildings, £8·35	0	11	9
Depreciation, 3 per cent. on line = £4·58	0	2	8
	3	3	0
Labour at sub-station and distribution charges ...	0	15	0
	£3	18	10

Of this sum, £1 2s., or about 30%, is on mains and sub-station account. Over-all efficiency, 89 per cent.

Consumer taking 613,200 units per annum at ·338d. ...	£865
Fixed charges, 3·9 × 100	390
	£1,255

Average price per unit, ·49d.

Consumer taking 70 k.w., mean load 10 hours per day: 255,500 units at ·338d.	£360
Fixed charges	390
	£750

Average price of ·7d. per unit.

Short-hour consumer: 36,500 units at ·338d. ...	£51	8	0
Fixed charges	390	0	0
Total	£441	8	0

Average price, 2·9d. per unit.

Summarising Tables I. to V., we have price of one unit delivered at low-tension 'bus bars for various classes of consumers, synchronous motor-generator, 15,000 line volts, and two three-core feeder cables.[1]

Table I.—(1) Consumer whose mean load is 70 per cent. of his maximum demand, and takes his mean load over 24 hours, can have his supply delivered to the low-tension 'bus bars for an average price of ·59d. per unit; (2) consumer who takes same demand and mean as above, but for 10 hours per day, ·9d. per unit; (3) ditto, but takes his maximum demand for one hour per day, 4·1d. per unit.

Table II.: Induction Motor-Generator.—Consumer Class 1, ·61d. per unit; Class 2, ·92d. per unit.; Class 3, 4·2d. per unit.

Table III.: Rotatory Converter.—Consumer Class 1, ·558d. per unit; Class 2, ·852d. per unit; Class 3, 3·95d. per unit.

Table IV.: Synchronous Motor-Generator, Three Line Cables.—Consumer Class 1, ·62d. per unit; Class 2, ·94d. per unit; Class 3, 4·32d. per unit.

Table V.: Six-Phase Rotatory Converter, Six Line Wires (Bare Copper). Consumer Class 1, ·49d. per unit; Class 2, ·7d. per unit; Class 3, 2·9d. per unit.

These figures give some idea of the commercial possibilities of distribution with various equipments in the sub-station and different lines. The predominant influence of the line is apparent in every case, and shows that the problem of economical power distribution is to a large extent a question of cables. The advantages to be derived from the use of a bare copper overhead line are so great, even when a pretty expensive line construction is adopted, that nothing but the very strongest reasons against their adoption should prevent the Board of Trade from permitting their use under more liberal conditions than at present. It is remarkable that the maximum price per unit which any supply authority may charge is fixed, while, on the other hand, restrictions are placed on the business from a commercial and engineering standpoint which make the cost of delivering a unit at a place distant from the generating station so great as to make the supply of short-hour consumers unprofitable. No legislative authority is justified in

[1] Instead of two cables, each having a capacity of 1,000 k.w., three of 500 k.w. carrying capacity may be used, as in Table IV., giving one cable spare, and although this would be an economical plan where copper predominated over insulation, costing approximately £750, as against £1,000 by the other method, yet insulation costs £16,500, against £13,000 by the lines having two cables. An interesting result showing that the largest cables are generally the most economical.

making the long-hour consumer pay for the short-hour consumer, nor is it justified, even to the very slightest degree, in imposing conditions upon a business which renders trading commercially unsound ; yet it is apparent that such would be the case if a low-tension network were tacked on to the sub-station under the conditions in Table IV. The capital charges, distribution, and other costs would make it difficult to deliver a unit to any short-hour consumer at much less than 6d., even, as is assumed, that the energy is generated at a station where every possible opportunity is taken to secure economical generation ; and, as will have been noted, the transmission efficiency is taken at very favourable figures.

A feature of some interest is the small difference between a rotatory converter and synchronous motor-generator equipment (Tables I. and III.). These come very close to each other in point of cost per unit delivered at the low-tension terminals. The total cost to the long-hour consumer differs by only £89, and the total capital investment by an equally small amount. Of course, the aggregate saving on the cost of the line and sub-station may appear fairly large, but each kilowatt of maximum demand only benefits to the extent of $\frac{1}{750}$th of the total saving. Nevertheless, it is of importance to the supply authority, as the saving of £89 per annum on the long-hour consumer is over 15 per cent. additional revenue on the capital invested by the company in order to supply that consumer, or giving the consumer the benefit of the saving, it means that he saves annually a sum equal to the investment of an additional £900 in his business. Taking everything into consideration, it is apparent that only the very strongest engineering reasons can justify the adoption of motor-generators in preference to rotatory converters. Such disadvantages as the latter may have are not at all serious, and do not, in the writer's opinion, justify their exclusion from a distribution system under ordinary conditions.[1]

It will be observed that the diversity of consumers' demands on the sub-station has been left altogether out of account in the foregoing paper. While recognising the advantages of a load where the maximum demand of all consumers does not occur simultaneously, or nearly so, the writer is of opinion that too much may be made of this point. A manufacturing district is seldom a residential district, and a moment's reflection will show that the maximum demand of such a district will occur, in winter, between 4.30 and 5.30 p.m. While, of course, that hour does not represent the period of maximum intensity of production in most manufacturing establishments, it, nevertheless, represents the maximum load, as, in addition to power, there is a large lighting load, due to works, drawing, and commercial offices. The writer has had many opportunities of observing this point, and he has yet to learn of exceptions. One large station supplying, through several sub-stations, residential and industrial districts would naturally derive some con-

[1] The motor-generators are all to one specification, and were built for the line pressure on the stator, which accounts for their price being higher than figures generally quoted. The three-phase rotatory is based on a machine having the same temperature rise as the motor-generators, while the six-phase rotatory is approximate.

siderable advantage from such a diverse demand, as has already been noted, but, as will be seen from the figures given, it cannot seriously modify the price per unit, as in most cases the high-tension feeders and sub-station, to which must also be added a low-tension network, will exercise a great, if not predominant, influence upon the commercial results.

Among other considerations, the question of depreciation in the high-tension cables, and the losses in their dielectric, are problems of considerable importance. Experience has fixed the depreciation in cables working at lower E.M.F.'s; but can we be certain that under the new conditions their life will be equally long? Not only so, but a much larger amount of money is spent on insulation, which has no scrap value; hence I think the figure of 5 per cent. is, if anything, low. The fact that energy is absorbed by the dielectric proves that some work is being done upon the insulation. What really does happen? The insulation may be chemically stable under the influence of high E.M.F.'s, or it may not. It may be that the rapidly alternating polarisation of the dielectric will cause the formation of new organic compounds, rendering the insulation at no very distant date incapable of withstanding the stress due to the working pressure. Were this so, long-distance transmission by underground cables would prove a financial failure, and one of two alternatives would be forced upon us—viz., overhead wires or a multiplicity of small stations. American experience with overhead wires and high voltages proved that the insulators were the crux of the question, and are not we in this country likely to have a similar experience under more difficult conditions? It may be urged that the question of dielectric hysteresis is dealt with in a rather arbitrary manner. This is intentional, as although it is not my wish to dogmatise on a question as yet far from being satisfactorily settled, it is necessary to take something for granted in order to give the paper definite shape. The capacity of the ·017 square inch cables has been taken at ·125 microfarad per mile and the power factor ·023. This gives rather less than 1 per cent. loss with the assumed load-factor. It should be noted that in Table III. 1 per cent. is allowed for the dielectric loss, which is, however, much too high, as 25 $\sim$ would be the periodicity in the line as against 40 to 50 in the other cases.

While collecting data for this paper, particularly with reference to the performance of the sub-station plant, I obtained some interesting figures on the cost of labour and repairs chiefly on systems employing converter sub-stations. In eight stations of which I had full particulars, 43 to 65 per cent. of all the labour charges on the system (generation + distribution) represented labour costs in the sub-stations, four stations were between 50 and 55 per cent. Of the repairs, in few cases was more than 5 per cent. spent in the sub-stations, often less. One engineer said his three sub-stations had been in operation eighteen months, and two had cost nothing in repairs. Of course, such data as are available have only been from stations of recent growth, and experience has been obtained chiefly with new plant, where the repairs are generally small; nevertheless, the figures are interesting.

The distribution of polyphase currents as such in the low-tension

network has not been touched upon in the paper, chiefly through lack of time; nevertheless, the writer is of opinion that the present system of converting alternate to direct current is bound, in the natural process of evolution, to be superseded by the simpler method of transformation from high to low pressures without conversion. Nothing can justify the investment of money in apparatus which converts alternate to direct current merely to pander to popular fancy. Any one having experience of a system where polyphase motors and lights are supplied from the same generator cannot fail to be impressed with the steady light from the incandescent lamps, and if 300 H.P. can be distributed as motive power by means of polyphase motors, and nearly 200 H.P. for lights in a large works, with every satisfaction to the drawing office —and that from *one* three-phase generator—there is no reason why, with a little more care than is exercised on a three-wire network, polyphase current for mixed light and power should not be distributed in a large town. Two outstanding advantages would be the elimination of a considerable proportion of the labour costs at the sub-station and a reduction of the capital invested therein.

In conclusion, the writer has to express his thanks to the Westinghouse Company, the British Insulated Wire Company, and numerous friends in this country and in America for information on various points.

Appendix A.

The annexed curves have been added since the main part of the paper was written. These show the relative cost of copper and insulation plotted for 300 k.w. and 600 k.w. transmitted ten miles with 10 per cent. line loss. It is apparent that the economic voltage is determined chiefly by the maximum power transmitted by any one cable. From the curves, it follows that if the maximum power transmitted by one cable be 300 k.w., 7,000 volts is more economical than the other voltages considered. With 600 k.w. 15,000 volts appears best. This latter figure does not, however, seem absolutely correct. From the diagram it appears that a very small increase in the cost of insulation would put the economic voltage back to 10,000. On consulting some very recent prices for high-tension cables by an English firm, I find that the quotation for cables at a voltage of 15,000 or 20,000 volts are higher than those used in plotting the curves in Fig. 2, placing the economic voltage for 600 k.w. at 10,000 instead of 15,000, a more likely figure, whilst 15,000 volts remains the most economical voltage for 1,000 k.w. Curiously enough, insulation becomes so costly that even at 3,000 k.w. per cable 20,000 volts would not be economical, so that unless with bare wires or excessively long distances, the latter is not at all probable in this country, and 15,000 volts is likely to remain the upper limit of good practice.

A remark made some time ago by Mr. Ferranti occurs to the writer. It was to the effect that the voltage which was best at one stage of a company's development would not necessarily be most economical at a later stage. This is supported by the curves given in the paper, for if a company wished to transmit 900 k.w. say ten miles by means of three

cables, each carrying 300 k.w., 7,000 volts would evidently be best. If, however, later developments necessitated the transmission of, say, 2,000 k.w., and four cables were employed, each carrying 500 k.w., 10,000 to 15,000 would be more economical than the original voltage. Bearing in mind the lines along which power distribution is likely to develop in this country, the choice of E.M.F.'s between 5,000 and 10,000 volts seems to be along safe lines, as the power transmitted per cable is more likely to be under 300 k.w. than over that amount.

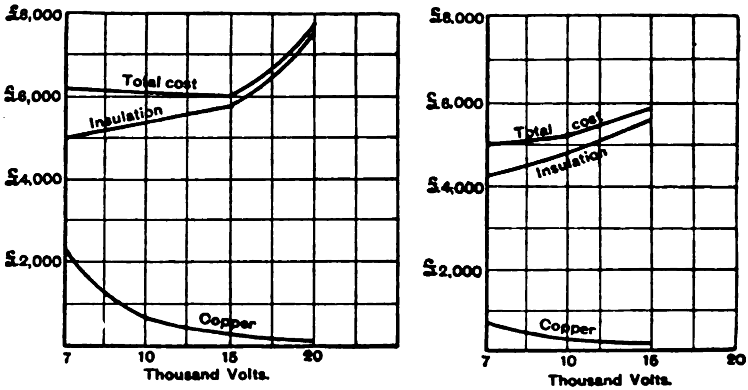


FIG. 5.

APPENDIX B.

List of some Electric Power Distribution Companies and the E.M.F. Employed, or to be Employed, in Transmission.

Company.	Voltage.
Central Electric Supply Company, London	6,000
Clyde Valley Electric Power Company	6,000
Cleveland and Durham Power Company	6,000
County of Durham Electric Power Distribution Company ...	10,000
Derbyshire and Nottinghamshire Company	—
Lancashire Electric Power Company	—
Midland Electric Power Corporation	7,000
Newcastle-upon-Tyne Electric Supply Company (Wallsend)[1] ...	5,000
Shannon Water Power Company	—
South Wales Electric Power Distribution Company	12,000
Yorkshire Electric Power Company	6,000–8,000

Where the voltage has been omitted the writer has been unable to gain any information on the point, or the question has not been settled.

[1] The Newcastle-on-Tyne Company have Parliamentary powers to go to 30,000 volts, but it is doubtful if such a voltage is economical except where the power to be transmitted is great and bare wires are employed on a private right-of-way.

Discussion, February 3, 1902.

Mr. Heaviside.

Mr. A. W. HEAVISIDE said that the paper raised many interesting points, not the least of which was the enormous capital necessary for equipment outside the generating station; the large power schemes seemed to sink enormous sums in mains and sub-stations. He suggested that Mr. Stewart might give them the cost of the four stages in detail, viz., generating station, transmission line, sub-station, and, if possible, also low-tension distribution—for the author had concluded his investigations at the low-tension busbars of the sub-station. This would enable them to take a bird's-eye view of electric power distribution. The lecturer had brought home very forcibly to their minds the fact that overhead wires for transmission and no conversion, only transformation, was the true solution of the problem, the latter getting rid of all moving apparatus and consequent heavy labour costs in the sub-station, while as for overhead wires he was at a loss to discover any real reason why they should not be permitted. It had been shown that the pressure on the overhead trolley system in large cities could kill a man, and if overhead trolley wires, admittedly dangerous, were permitted in the streets of large cities, why prohibit high-tension overhead trunk lines for power? It mattered nothing to the man who was killed, whether he was killed with 500 or 5,000 volts, the result was the same; and in country districts there was not the slightest doubt that high pressures were less dangerous than trolley wires in our streets. The problem in construction lent itself to safety as compared with trolley wires, inasmuch as large-gauge, and hence strong, wires were needed, and Y-shaped supports were their own guards. Such high-tension wires hung undisturbed, whilst trolley wires were being knocked about, even violently, by the pole. He had known 800 lb. to the mile copper wires defy storms and uphold the trees that the storm had blown upon them. Inductive troubles might be very great, but by no means insurmountable.

Mr. Dobbie.

Mr. R. S. DOBBIE thought the paper of great value at this stage, and was much impressed with the enormous sums necessary for insulation. He could not help thinking that were American work limited in the same manner as British, the great developments which had taken place in that country would never have been known. Mr. Stewart had very ably summed up the relative merits of various types of sub-station equipment. One point, however, he had overlooked was that, given all three types, similarly rated as regards temperature-rise, &c., the rotatory converter was capable of withstanding much more severe overloads than either synchronous or induction motors. The latter would fall off in speed to a serious extent, and the former drop out of step with about 25 per cent. overload, but the converter would stick to its work even under much more difficult conditions (75 per cent. to 100 per cent. overload). The question of supplying consumers with polyphase instead of direct current was a question of no small importance. Supply authorities must afford the kind of current consumers wanted, and there was a distinct preference for direct current. The problem of satisfactory speed regulation with alternate-current motors had not

Mr. Dobbie. yet been solved, and as many industries required wide speed variation, he considered that all-round satisfactory service could only be given with direct current. From his American experience he felt quite sure the day had not yet arrived when the consumer would uncomplainingly accept polyphase current from a supply authority, especially if a direct-current system was available. Moreover, it was still a fact that polyphase alternate-current motors cost more than direct-current machines, which was another reason against them. An interesting point raised by the lecturer was the wave form of the apparatus. He quite agreed with Mr. Stewart on this point, although it was very generally overlooked. Many types of alternators did not give waves even approximating to a sine curve, and different makers' apparatus gave different wave forms, and the result was anything but satisfactory when several makers had supplied plant for one installation. Some time ago, when in the States, he (Mr. Dobbie) designed an alternator which he flattered himself gave a sine curve. He was interested, however, some little time ago to receive from a friend in London the description of an unusually good oscillograph which showed that there was a distinct step in the E.M.F. as each slot came within the magnetic field, even in a machine with a continuous-current winding, which was the case of the machine in question, where there were comparatively many slots per pole.

Mr. Snell. Mr. J. F. C. SNELL (*Chairman*) said the author seemed to have made out an excellent case for the rotatory converter; his diagrams went further, however, and rather operated against long-distance electric power transmission. In England, apart from all other considerations, the enormous cost of duplicating a feeder—and that was a necessity—was so great that it must act as a deterrent to the development of long-distance transmission. He also noted that the line and sub-station cost nearly twice as much as the generating station electrical plant. Mr. Snell then proceeded to point out that in central station work the curve of total costs was hyperbolic in its nature, and after a certain critical point had been passed, capital charges became almost a fixed figure. Opinions differed as to where the critical point was: from calculations he had made he thought that in the region of five million units per annum would be found the critical point. Mr. Snell questioned if it were possible to generate at 0·3d. per unit. Taking the lowest costs he could think of, it seemed almost impossible to generate at that figure.[1] Rates and taxes in most towns swamped the figure with a charge of about ¼d. per unit. The author had concluded his investigations at the low-tension busbars, hence the figures given did not represent cost to the consumer. It must be borne in mind that that would add about another third to the figures given—in fact it did not seem possible, even on the most advantageous terms, to supply a consumer at less than 1¼d. average per unit. After referring to the influence of insulation on the cost of cables, Mr. Snell pointed out how interesting it was to note the critical limit to the pressure, and asked what was the critical limit to the pressure when bare wires were used. Referring to the life

[1] The figure 0·3d. refers to *works costs* only.

of extra high-tension cables, they knew that both rubber and paper suffer from molecular strain, and he thought that the dielectrics of these high-tension cables would age much more rapidly than had been expected. Rubber, for instance, aged rapidly under high alternating E.M.F.'s; paper might do so more slowly, but it could not be doubted that it suffered in the same way. He suggested that some attention might be given to the question, and one might formulate a law for molecular fatigue in a dielectric, as was done for iron and steel. He did not agree with Mr. Stewart's figure of 38 per cent for a load factor except in most unusual cases. In Sunderland they had 800 H.P. to 900 H.P. of motors, giving a load factor of 18 per cent. lighting at 11 per cent.; the tramways gave a load factor of 35 per cent., but the whole load factor was only 15 per cent. Taking any large power scheme, they could only expect a good load factor due to diversity, and not to steady demand from consumers. His own opinion was that power schemes could not expect over 25 per cent. all round. He believed that one station in connection with a power company obtained a load factor of over 40 per cent., but that, Mr. Snell thought, would certainly come down, as the area of supply was extended to include lighting and general consumers; this was, in his opinion, the weak spot of all power schemes. The mere fact that at the moment a station supplying works, &c., close at hand had a good load factor did not prove anything; he was quite sure that such schemes could not compete with well-managed stations of moderate size. Sunderland, for instance, had been left entirely out of account by one of the power companies, as it was admitted that they could not compete with the town supply. The paper was, he thought, most interesting at this stage, and shed new light on a subject regarding which little was known. He had great pleasure in calling upon Mr. Stewart to reply. Mr. Snell.

Mr. A. STEWART, in reply, said he was exceedingly pleased to have such interesting, though, as might be expected, not altogether favourable expressions of opinion on the two important details of power distribution, viz., the line and sub-station. That opinion should differ is only to be expected, and he would have been delighted to hear the views of many engaged in the design and construction of such schemes. In reply to Mr. Heaviside, the cost per k.w. *installed* of the scheme outlined in Table 1 was as follows: Generating station £25, line £15·7 sub-station £6·5 while per k.w., maximum demand, which is the figure determining the commercial success of the system, the generating station becomes £20·8, line £26·2, and sub-station £10·7, and the losses at full load are as follows—in line 5 per cent., in sub-station 14·6 per cent., giving an over-all efficiency— Mr. Stewart

$$\frac{\text{Power delivered at low-tension bus-bars of sub-station} \times 100}{\text{Power given to line at generating station.}} = 81{\cdot}2 \text{ per cent.}$$

This was if anything rather better than would be found in practice, a remark applicable to the results right through the paper due to the conditions assumed being practically non-existent in any station. The results in their relation to each other were, however, accurate, and this is what was aimed at, in order to bring out the relative commercial

Mr. Stewart. advantages of each type of apparatus as near to practical conditions as could be calculated.

He quite agreed with the various speakers that overhead wires are an economic necessity. Legislation against them is merely indirectly taxing the progress of the industry.[1] He did not agree with Mr. Dobbie on the necessity for direct current on the low-tension side of the system, especially in small towns where the motor load is unimportant. The price of polyphase motors is not of serious importance, and would hardly be noticed by consumers, while as the Tesla patents expire soon the price of such motors will fall probably to the level of direct-current machinery due to stress of competition. The other objections to polyphase distribution were not at all serious, as those doing such work on the Continent could testify, while the three-phase factory installations in this country, combining lighting with power, also afforded examples (with some exceptions however) of satisfactory polyphase distribution for mixed power and lighting. It might be said with much truth that the power factor of public opinion on this point was low; in other words, the apparent objections were largely in excess of the real objections. In reply to Mr. Snell, he did not start out with any bias in favour of converters, but rather for synchronous motor generators. It cannot be questioned, however, that in most cases, if engineering considerations permit, converters will prove superior to anything else, that is, if one must convert to direct current at all. Mr. Snell's opinion on the difficult problem of one station *versus* several, was of considerable value, representing the product of years of observation. One remarkable instance was Glasgow, where after considering this point Mr. Chamen proceeded to build two new stations, making four altogether owned by Glasgow Corporation, within the city for electric light and power purposes, while for tramway purposes one large polyphase generating station supplied the necessary power to sub-stations. The difference in operating conditions makes comparison difficult, indeed altogether impossible, but in all probability this diversity of operating conditions gives the reason for the dissimilarity in practice. The cost of a unit given in the paper as ·3d. referred to *works* costs only, rates, taxes, &c., being left out of account altogether. A works cost of ·3d. per unit is not at all difficult to obtain on a load factor of over 30 per cent. with well-proportioned units. Mr. Snell's opinion that the low-tension network exercises very great influence on the costs is, I am sure, quite right, but it must not be forgotten that with good load factors, the low-tension side was earning money over a much longer period, hence the incidence of capital charges on costs per unit are not so great. The load factor which I have chosen refers to *a* particular sub-station and *not* to the whole system. It was, moreover, quite a reasonable one, and for a sub-station supplying some kinds of industrial works might even be higher, for instance, shipbuilding and engineering works running a double shift give load factors varying from 35 to 56 per cent., depending upon the size of the night shift. Hence were the area supplied by a sub-station to

[1] Since the paper was read and discussed the B.O.T. have announced that they will, under certain conditions, permit overhead wires.—A. S.

Mr. Stewart.

include power supply to such works, the load factor would be considerably over the figure taken.

The question regarding the fatigue of a dielectric was very important, and a law governing it would be of some value, unlike iron and steel. However, most dielectrics had a rather complex chemical composition, and with age there also comes a chemical change which might altogether alter its physical properties. The mere fact that work is done on the insulation proves that some change takes place. He had discussed it with many of his friends, both cable-makers and chemists, and the chief point of disagreement was whether the change was molecular fatigue or chemical change. He felt sure that it was the latter, but many say it is molecular fatigue due to the repeated reversal of stress on the insulation. In the absence of data on this point the discussion upon it might rise to the level of a purely academic discussion; experimental data should not be long in coming forward, as even if overhead wires should in many cases supersede underground cables, there is still sufficient at stake to justify an investigation of the chemical and physical properties of various insulators under rapidly alternating high E.M.F's.

DUBLIN LOCAL SECTION.

NOTES ON IRISH WATER-POWER AND ITS ELECTRICAL DEVELOPMENT.

By W. TATLOW, M.A., B.E., Associate Member.

(*Paper read at Meeting of Section February* 13, 1902.)

The fact that no coalfields of any great importance exist in Ireland, and that in consequence fuel for the operation of steam or gas engines has to be imported at considerable cost, causes attention to be directed to the other possible means of obtaining motive-power.

The utilisation of the water-power of the rivers naturally suggests itself first owing to the great success which has attended the large electrical water-power schemes which have been carried out during the last few years both in America and on the Continent.

The existence of water-power in Ireland has already exerted an important influence on the electrical industry, as undoubtedly the chief inducement to the construction of the Portrush and Giant's Causeway Railway, the first commercial electric line, was the possibility of obtaining the necessary motive-power from the Waterfall at Bushmills; and it is probable that the Bessbrook and Newry Railway which was built very shortly after similarly owed its origin to the existence of the stream which provides the necessary power. It can, moreover, scarcely be doubted that many of the smaller electric light undertakings throughout the country, as for example at Galway, Killarney, Kenmare, Carlow, Bray, and Boyle, would never have been set on foot had it not been that water-power was available, and indeed to a certain extent already developed in the majority of these instances. Owing to the preponderance which electric lighting has had until quite recently over the other branches of electrical industry the importance of water-power for producing electrical energy has been greatly underestimated.

The demand on electric light stations being only for a few hours per day, the cost of fuel for working heat-engines may be a much less important factor than the interest on capital sunk in the development of water-power, together with the stand-by plant which it is often necessary to provide in case of failure of the water-power owing to floods or drought. When, however, it is a question of the operation of railways or the driving of factories which require power nearly all through the day, and more especially when it is desired to supply electro-chemical works which run twenty-four hours a day all through the year, the advantage of water-power, when the necessary capital outlay is not abnormally great, becomes very conspicuous. This argument is borne out by the fact that on the Continent out of a total of 166,000 H.P. expended on electro-chemical work, 149,000 is obtained from water-power. The amount of labour required for the operation of a water-power plant should also be much less than for a steam or

gas plant of the same dimensions, and a less skilled type of labour will for the most part suffice, such as is required for the moving of sluices and the cleaning of straining racks.

Although at the present time the electro-chemical industry as a whole cannot be said to be in a very prosperous condition owing to the over-production of calcium carbide, yet there can be no doubt that electro-chemical processes will within a few years supplant many of the older methods of producing chemical products, as has already happened in the production of aluminium and potassium chlorate, and in the purification of copper, and to a partial extent in the manufacture of phosphorus, caustic soda and bleaching powder ; not to mention the large group of products which are only capable of being formed at the high temperature attained in the electric furnace, and in the manufacture of which there is no competition with an alternative method.

The water-power of our rivers when properly developed and controlled will place Ireland in a position to compete in many of the chemical industries from which she was hitherto debarred owing to the large quantities of coal required for working the older processes. It is encouraging in this connection to reflect that we have already a chemical factory in Cork which produces high-grade chemicals of great purity and even exports some of these products to Germany, as showing that the technical ability to carry out manufacturing work of this class can be found amongst our countrymen.

As regards the capital which it is permissible to expend on hydraulic works per H.P. developed, this depends on a large number of factors, such as the local cost of fuel and the fuel consumption of the class of heat-engine which could be used as a substitute, also on the load-factor of the demand for power and on the reduction which the water-power might be subject to either from drought or from back water, so that each case must be considered on its own merits. The highest capital expenditure on the development of water-power appears to have been at Lyons, where it amounted to £84 per H.P. developed, and it is said to have been as low as £3 9s. 3d. at Vallorbe in Switzerland, and even lower in Norway, so that an extremely wide range has been covered ; nevertheless for the operation of electro-chemical processes requiring, as they mostly do, a large number of units per ton of product an expenditure at all approaching that at Lyons would be quite out of the question. At Niagara, where the capital expenditure was fairly moderate, a horse-power is supplied to large users at the rate of £4 per annum, yielding a profit to those producing the electric energy ; and electro-chemical industries are successfully carried on which buy their electric energy at this price, which amounts to 0·146 pence per unit if the supply is used continuously.

In considering this question it is important to notice that the capital expended on the development of a water-power in this country would be distributed chiefly among the labouring classes, giving employment which would help to retain and ameliorate the condition of the dwindling population, whereas an annual outlay on fuel is money sent directly out of the island.

It is necessary at this stage to endeavour to take stock of the water-

power which can commercially be made available in Ireland either directly or by the aid of electrical transmission. The water-power of a country is dependent on the rainfall, the area of the surface, and its mean elevation above the sea level, and also on the nature of the soil. The rainfall varies considerably over Ireland, being greatest in the south-west and least on the east coast. It averages in Dublin about 30·9 inches, in Belfast 35 inches, Cork 40 inches, Sligo 42 inches, Killarney 53 inches. In mountainous districts it reaches higher figures, such as 83 inches in the Butter mountains at the head of the Upper Bann, and it has been taken roughly to average 36 inches over the whole island; of this about one-third or 12 inches is carried down to the sea by the river system. Sir Robert Kane estimated the average elevation of the land surface of Ireland at 387 feet, and calculated from that, together with the total area twenty million acres, and the assumption that one-third of the rain flowed away to the sea, the total physical water-power of Ireland at 1¼ million horse-power.

It is difficult to gain any idea of what proportion of this quantity could be practically utilised, but a rough idea may be obtained if the actual condition of some of the larger rivers is examined, so as to discover what proportion the total fall which could be made available for working turbines on these rivers bears to the mean elevation of their catchment areas or to the mean elevation of the whole surface in absence of the above figure. The Shannon and the Erne may be taken as examples. Both these rivers flow many miles with a sluggish current and descend rapidly into the sea within a few miles; the Shannon descending 97 feet between Killaloe and Limerick, and the Erne 150 feet in five miles between Belleek and Ballyshannon. It is obvious that a large part of such fairly rapid falls is capable of development.

In the case of the Shannon it is proposed to use 40 out of the above 97 feet under the new Shannon water-power scheme, and it is possible that a further quantity of power might be developed at other parts of the river above Limerick. In the case of the Erne it is certain that at least 60 to 70 feet of fall could be utilised between Lough Erne and the sea. These facts would lead one to expect that, taking into consideration the falls available on the upper part of these rivers and their tributaries, a fourth part of the total mean fall could by suitable engineering works be made available. Admitting this, there would be an average of 300,000 H.P. available day and night all the year provided the whole discharge of the rivers could be economised.

The above figure would require to be greatly reduced owing to the fact that large quantities of storm water necessarily pass away unutilised, and it is doubtful if more than half of the total discharge of the rivers could be utilised unless special provision is made for the storage of storm water and the discharge of the latter during periods when the flow of the rivers is below its average value. In his paper on automatic sluices, Vol. XIX. *Proceedings of Civil Engineers, Ireland*, Mr. Dillon gives 0·488 cubic feet per acre per minute as the ordinary flood discharge in February of one of the rivers draining the central part of the island, and 0·08 cubic feet per acre per minute as the minimum discharge in

September—these figures show the very wide range over which the discharge of the rivers varies, the ordinary maximum being more than six times the minimum flow, apart from the question of extraordinary floods which occur about once in ten years.

The quantity of water-power actually in use in Ireland in 1839 was 2,147 H.P., and to judge by the number of abandoned corn-mills to be seen throughout the country it is probably not enormously greater to-day. There would appear to be about 800 H.P. of water-power in use at present for public electric lighting purposes. There is therefore a great field still open for engineers and capitalists in regard to the development of our resources in this direction.

The practical question must now be faced as to how and where this power is to be made commercially useful.

There are several places such as Galway, Ballyshannon, and Ballysadare where the fall to be used is into the sea itself, and where the site is suitable for building factories such as electro-chemical works. Other falls, such as those on the Shannon near Limerick and at the weirs on this river at Athlone and elsewhere, have the advantage of being situated on an extensive inland navigation in communication with the sea. A large number of places where power is available are not, however, so favourably situated, and it would be necessary to construct transmission lines to carry the power to the nearest town or to points on the railways or canals which were suitable for the establishment of factories.

When transmission lines of any great length have to be constructed, their first cost, maintenance, and difficulties as to way-leaves may often prove so serious that it would not be worth while to construct them unless a considerable amount of power was to be transmitted. These considerations seem adverse to the utilisation of many of our smaller rivers which do not yield more than, say, 50 H.P. at any point when the river is at average height. Very constantly, however, we find two or more natural falls or rapids in the same locality. In other places the rivers have been systematically laid out with weirs every half-mile or so, giving a fall of from 5 to 10 feet at each, by means of which corn-mills were formerly worked. In such cases it is quite feasible to gather up the power from the different points by means of a line running along the river bank, and then to transmit the sum total to a considerable distance if necessary.

This collecting system is just the converse of the ordinary system of distributing power from a central station; and having regard to the large scale on which the most successful modern factories of almost any kind are worked, and also to the large quantity of power required for electric furnace work, it is probable that much of our water-power will have to be dealt with in the above manner if it is to be used with the best advantage; and the same arguments would apply if it should ever prove economical to operate the railways of the country by means of electricity.

Great simplicity in the generating plant would be essential to the success of the above system, as specially skilled men could not be employed at a number of small generating stations, and it has suggested

itself to the author that this difficulty could best be overcome, in the case of transmission by three-phase alternating current, by using an ordinary three-phase generator in the more important power-house, and having three-phase non-synchronous motors driven as generators in the smaller outlying generating stations. This would reduce the complication of these small stations, as there would be no exciters with brushes and commutators, and no accurate synchronising when starting up, the attendance being reduced to the lubrication of bearings, and the moving of the sluices and cleaning of straining racks. Some trouble would probably arise owing to sudden variations in the load, but this might be arranged for by means of artificial loads at the main power-house; and gradual alterations could be provided for by telephoning instructions to the attendants in charge of the auxiliary generators. As examples of places where some such a system of concentrating power would be suitable, one might point out the two adjacent falls on the Liffey at Poulaphuca and Ballymore-Eustace, the two falls at Colloney and at Ballysadare near Sligo, and the system of weirs on the Nore near Kilkenny.

The simplest application of such a system presents itself where a large factory on the banks of a river, deriving part of its power from water and the rest from steam, might gather in power from other points either up or down stream, and thus be able to dispense with the auxiliary steam-power. Unfortunately there are in this country many more derelict mills than working ones, and cases where the above arrangement could be carried out are not infrequent. The tail races of these old mills are, however, as a rule, miserably small and shallow, and being as a rule carried beneath the building itself, it is both costly and dangerous to enlarge and deepen them. It will be found that this is the one circumstance which greatly reduces the value of these old mills for power purposes.

As regards transmission lines, overhead wires of bare copper run on insulators would appear to be the right thing except in the immediate vicinity of towns, particularly as many of the lines would require to be made across country over bogs and streams where a cable would be out of question.

It would appear that under the existing rules of the Board of Trade an overhead line carrying more than 30 kilowatts cannot be made without special sanction, and should this be so it shows that rules which are found suitable in a thickly populated country such as England are very unsuitable here. It would in any case appear to any one reading the rules and regulations affecting the development and transmission of electric power in Great Britain that these are much more numerous and stringent than those affecting other enterprises which really involve greater risk to the community, such, for example, as the construction of water works and gas works, and the carriage and storage of large quantities of coal and timber; and a person having no technical knowledge of the subject would naturally think, after reading these regulations, that the supply and use of electricity was a most dangerous business which, if it could not altogether be prevented by law, should at least be discouraged as much as possible.

Turning now to make a detailed examination of the system of rivers and lakes which drain the country, I would like at this point to remark that there appears to be a great need of a proper survey of our rivers, including both the measurement of falls at various parts of their courses, and also the keeping of records of the water levels and discharges at all seasons, together with measurements of the rainfall over the catchments. Such information would not only be useful for the utilisation of the water-power, but also for determining the nature and extent of drainage works on which large sums are spent in this country from time to time. As an example, I may mention that the engineers who carried out the Erne drainage at a cost of £120,000 were greatly indebted to Mr. Porter, of Belleisle, Co. Fermanagh, who had kept daily records of the level of Lough Erne for many years.

It is possible that the local constabulary might be employed at a small expense to keep such records, provided that proper scales were fixed in the rivers for reading the water levels from which the discharge might be computed by an expert, and each barrack might also be provided with its own rain-gauge. The information thus gained should be published from time to time in a form convenient for reference. At present there does not seem to be any published work on the subject of later date than Sir Robert Kane's book on the *Industrial Resources of Ireland*, published in 1845. The collection and publication of such information might well be taken in hand by our new Department of Agriculture and Technical Instruction, which is devoting so much attention to the re-establishment of local industries.

The following list of our chief rivers, giving the area of their catchments, is taken for the most part from Sir Robert Kane's book:—

RIVER.	AREA OF CATCHMENT.		
The Shannon	Total	4,500	square miles.
„ above Killaloe	„	3,600	„
The Barrow, Nore, and Suir	„	3,400	„
The Erne	„	1,580	„
The Foyle	„	1,470	„
The Corrib	„	1,370	„
The Blackwater	„	1,220	„
The Moy	„	1,030	„
Blackwater and Boyne	„	1,080	„
The Slaney	„	815	„
The Lee	„	735	„
The Blackwater (Armagh)	„	626	„
Liffey, Dodder, and Tolka	„	570	„
The Main	„	277	„
Ballysadare River	„	250	„
Ballinderry „	„	166	„
Upper Bann „	„	134	„

Assuming that twelve inches of rain flows away annually through the rivers, it will be found that the drainage of 13·7 square miles will

give an average brake horse-power per foot of fall assuming that the turbine has an efficiency of 75 per cent.

The above efficiency is chosen both because it is well within the results obtainable with good turbines, and in larger installations with considerable fall it should cover the loss of conversion into electrical horse-power, and also because it corresponds with the simple and useful formula, that an acre flooded one foot deep can give one horse-power hour per foot of fall.

A calculation on these lines would make the average flow of the Shannon at Killaloe equivalent to 260 H P. per foot of fall.

It is important to note that the majority of our rivers have lakes of considerable size connected to them. (See table appended.) These not

TABLE GIVING LEVELS AND AREAS OF PRINCIPAL LAKES, AND RIVERS THROUGH WHICH THEY DISCHARGE.

River.	Lake.	Level.	Area in Acres.
Shannon	Allen	146	8,900
	Ree	122	26,428
	Derg	108	30,000
Erne	Lough Gowna	214	3,031
	„ Oughter... ...	160	3,076
	Erne (Upper)	151	8,739
	„ (Lower)	150	27,645
Lower Bann	Neagh...	46	96,000
Moy	Con and Cullin... ...	40	14,000
Corrib...	Mask and Carra ...	51	26,260
	L. Corrib	14	50,700
Tributaries of Shannon... ...	Owel	329	2,527
	Ennell...	274	3,600
	Sheelin	209	4,530
	Derravaragh	209	2,974
	Iron	204	479
Blackwater	Ramor...	277	1,842

only aid naturally in equalising the flow of the rivers and reducing the violence of floods, but they are also capable of being used in many cases as storage reservoirs in which storm water can be impounded, and discharged when the natural flow of the rivers is insufficient for power purposes. The greater the elevation of the lake, the greater its value in this respect. It has often been proposed by means of such natural or artificial reservoirs to store up the winter and midsummer floods and hold them over against the very low water which occurs in the rivers at certain seasons, generally in September, and thus to increase the minimum flow of the river.

This method of using reservoirs is based on the idea that the power of the turbines is to be limited to the minimum flow, which is a very wasteful arrangement, as during the greater part of the year much water will pass away unused. A better plan is to make the turbines sufficiently large to absorb at least the average flow, and to provide

auxiliary steam, gas, or oil power if it is necessary to work at full power during dry seasons. Using the latter plan the storage reservoir should be drawn upon whenever the natural flow fell below the average, and this would permit of a much greater amount of storm water being caught and subsequently used with a reservoir of moderate size, as the latter would be partially filled and emptied many times in the year, and would be generally in a condition to impound water and reduce floods, which are nearly as objectionable to the mill owner as to the agriculturist.

Artificial reservoirs for power purposes have been constructed on the upper Bann, which rises in the Mourne Mountains at an elevation of over 2,000 ft., and in its descent to Lough Neagh drives numerous linen and flax mills. The Lough Island reservoir, at an elevation of 430 ft., was constructed in 1839 on the site of a natural lake over which a head of 35 ft. of water was raised by an embankment to form a reservoir covering 259 acres and of a capacity of 270,000,000 cubic feet. The Corbett reservoir, further down on the same river, was constructed in 1847, whereby a head of 11 ft. 3 in. was raised over an area of 70 acres.

These works, an interesting account of which may be found in a paper by Mr. Smyth in the Transactions of the Institute of Civil Engineers of Ireland, June 13, 1869, cost about £30,000, and a rate of £10 per foot of fall was levied on the owners of linen mills and £5 per foot fall on the owners of corn and scutch mills benefited by the increase flow; 180 ft. out of the total fall of 350 ft. appear to have been thus rated, showing that fully one-half of the natural fall of the river was utilised in the case of the Upper Bann. These works were considered economical and satisfactory when made, but it must be borne in mind that at the time of their construction a steam horse-power for working mills of this kind was estimated to cost about £30 a year.

In connection with the Rathmines waterworks a reservoir has been constructed at a more recent date to impound the storm water of the upper part of the Dodder from a catchment of about 6,000 acres, the store thus accumulated being subsequently sent down the river in compensation for the water abstracted for the supply of Rathmines. At one time a total fall of 370 ft. was occupied by mills on the Dodder, twenty-eight in number, making paper, flour, cloth, etc., the total power being about 900 H.P., but being very precarious owing to the nature of the river, which dries up very rapidly in the absence of rain. Many years before the construction of the Rathmines waterworks it was under consideration to construct a storage reservoir at Glenismaul for power purposes only, which it was expected would have raised the total power of the river to 2,000 H.P., but the reservoir was never constructed. It would, however, be interesting to discover, if possible, how and to what extent the operation of the existing compensation reservoir has affected the available power.

Where natural lakes are to be used as reservoirs it would generally be necessary to deepen the discharge outlet so as to use the existing water surface as the maximum level and to be able to discharge the lake down to a lower level by a means of sluice gates when water was

required, as in the vast majority of cases the raising of the existing levels of lakes would injuriously affect the drainage of agricultural land.

It would, however, be conceivable when the fall of the water from a lake used in one or more power-houses was considerable that it would be more economical forcibly to discharge the lake by means of centrifugal pumps driven by heat engines, during times of exceptional drought, instead of employing such engines as stand-by plant in the mills themselves. It may be mentioned in this connection that it has been proposed to obtain a range of level of 2 ft. on Lough Ennell for improving the power derived from Brosna, and more recently to use Lough Allen as a storage reservoir in connection with the Shannon power scheme, a use for which it is specially suited, as the land rises steeply around the shores of the lake.

The levels of several lakes have already been controlled for drainage purposes, notably Lough Erne, the outfall of which at Belleek is provided with four sluices 29 ft. wide by 15 ft. high, made on Mr. Stoney's plan with rollers and operated by a small turbine; these are opened in time of heavy rain to prepare the lake for receiving the floods coming down into it, and are closed when the water is low in order to maintain the navigation, which extends over some sixty miles, on one level. Needless to say these sudden violent discharges would not benefit works using the power between Belleek and the sea.

I propose now to give a description of a few places which I have had the opportunity of visiting where there appears to be water-power capable of being developed at reasonable cost, but which has up to the present been only partially used, or not used at all; it must, however, be borne in mind that in the absence of reliable information it is necessary to see a river both in flood and in drought in order to form a true estimate of its value for the generation of power.

One must also remember that a small river is not to be despised provided a good fall and storage facilities can be obtained. For example, the river used for making aluminium at Foyers has a catchment of but little over one hundred square miles, being comparable in this respect with the Upper Bann; but having a magnificent fall of 350 ft. and a storage reservoir capable of holding a supply for fifty days and nights' continuous working, it has proved itself a water-power of very great importance.

One of the most attractive-looking water-powers I have met with is the outfall of the Ballysadare river, which enters the sea some 4½ miles from the town of Sligo. I have roughly measured the catchment area of the two rivers which unite a short distance above this fall, and find it about 250 square miles, which should give an average flow equivalent to 18 B.H.P. per foot of fall. The smaller of these two rivers drains Lough Arrow, which might possibly be used to some extent as a reservoir. The water descends a steep rapid at Ballysadare, at the bottom of which it pitches over a cliff into the sea; the total fall, as near as one could judge by eye, must be at least 60 ft. Two corn-mills, one on each side of the river, use a portion of the water, and a mere fraction of the fall, the total power of which must average about 1,000 H.P. if my estimate of the levels is correct. The larger of the two streams

which unite above Ballysadare has a good fall on it at Collooney, about two miles distant, and works were in progress some two years ago for developing the surplus power there, a portion being already in use driving a large corn-mill. The head available is at least 40 ft. Both the Ballysadare and Collooney falls are situated in close proximity to railway stations; they are, moreover, so near to Sligo that the power from either or both might be used for lighting that town. Some thirty miles to the north-east we come to another water-power of greater magnitude, but one which would involve much greater engineering works for its complete development. I refer to the outfall of the river Erne, which enters the sea at Ballyshannon.

Here the river running over a compact limestone rock takes a final leap into the sea, the fall being about 10 ft. at high water and over 20 ft. at low water, and the average flow being equivalent to 120 H.P. per foot of fall, so that there should be from 1,200 to 2,400 H.P. available, according to the state of the tide. Two mills are in existence at this fall capable of using between them 250 H.P. at most. Owing to the great value of the salmon and eel fisheries in the river it is doubtful whether any large hydraulic works could be undertaken without buying up these fisheries at a heavy cost in the first instance. The operation of the drainage sluices at Belleek has also to be considered, as they cause excessive discharges through the river when opened to any extent. About a mile higher up the river there is a considerable natural fall called the Falls of Lora where the water rushes through a narrow rock channel, and possibly a fall up to 15 ft. might be obtained here. The whole course of the river from Belleek to the sea is rapid, with steep banks, and should therefore lend itself to the development of power by means of weirs suitably placed. At Belleek itself a fall of about 12 ft. exists between the lake and the river, and a small fraction of the water is used to drive the pottery works producing the well known Belleek china, but the vast bulk of the water passes continually through a byewash without doing any useful work.

The average natural power between Lough Erne and the sea cannot be far short of 18,000 H.P., and being distributed in the short distance of five miles a very considerable portion of this should be capable of being used. Higher up on the river Erne there are falls at Butler's Bridge in Cavan, and on a tributary, the Annalee, near Ballyhaise; there must also be available power between Lough Gowna and Lough Oughter, as there is a fall of 54 ft. between these lakes. I have not, however, seen these places.

If we turn now to the Galway district we find the river Corrib, draining some 1,370 square miles, falls into the sea in the town of Galway, the fall being about 14 ft. Some of the power is in use, and possibly in summer there is scarcely enough power for the existing mills, since the electric light station, which has 200 H.P. from the river, has also a gas engine as a stand-by. During a large part of the year, however, a great body of surplus water passes down into the sea.

A greater and more reliable water-power could be obtained in this district by using the fall of some 37 ft. which exists between Lough

Mask and Lough Corrib. The overflow from the former lake at present passes by an underground river into Lough Corrib near Cong, where the distance between the lakes is about two miles. A considerable proportion of the whole catchment of the Corrib river, 1,374 square miles in all, delivers into Lough Mask, and it is probable that as much as 2,500 continuous H.P. could be obtained here provided it were possible to prevent any great leakage between the two lakes. There is, moreover, a great advantage in drawing water direct from a lake, as in this case, instead of from a river, since the water can be expended rapidly or slowly as required, and whenever the turbine is not in use the water is being stored, provided the lake is not overflowing; the large size of the lower lake at the same time would prevent inequalities of discharge affecting the outflow at Galway. Although Cong is situated in an out-of-the-way place, yet the navigation of the Corrib river and lake would enable materials for manufacturing purposes to be brought cheaply to and from the sea at Galway.

There is said to be a fall of 27 feet at the outfall of the lakes Conn and Collin, which discharge by the river Moy in North Mayo and form a counterpart to the Galway lakes, but I have no precise information on the subject.

The lakes in the Mullingar district are of importance in connection with our subject owing to their comparatively high level. The highest, Lough Owel, is 329 feet over the sea, and serves to feed the top level of the Royal Canal, the water of which I believe is used to run the lighting of the railway station at Mullingar, the canal level at this point being some 50 feet over the Brosna, into which the tail water is discharged. The above-mentioned canal, as it approaches Dublin, passes over the Rye river at Leixlip station at a very considerable elevation,[1] and a valuable power could be obtained here by discharging the surplus water of the canal. The long levels on the canal at this point would act well as storage reservoirs, and power for lighting the terminus at Dublin, and possibly for lighting and driving the railway works, might be so obtained; the average power would be chiefly limited by the effect of flow in the canal upon the haulage of boats.

The mention of Leixlip brings to one's mind the river Liffey, which here presents so pretty a picture. The total fall on the Liffey at the Salmon Leap must be some 35 feet, and as the river at this point would seldom have a flow less than an equivalent to 12 H.P. per foot of fall, the available power should amount to 400 H.P.; a portion of this power is already in use, but there should be at least between 200 and 300 H.P. surplus. The upper portion of the catchment area of the Liffey in the Wicklow Mountains is of such a nature that the water flows off rapidly into the river after rain, like water off the roof of a house, and the river is subject to freshets of short duration after a few hours' heavy rain at any time. This was very striking after the dry weather last summer, as two or three freshets came down the Liffey before the small streams in the Meath district which had dried up began to flow again. It is certain that much more than one-third of the rain-

[1] 80 to 90 feet.

fall over the catchment above Poulaphuca passes to the sea through the river, as it is known that as much as 60 to 80 per cent. of the rainfall may run off from granite rock and moorland, of which a large part of this area consists. Should it, therefore, ever be contemplated to develop the power of this river in a systematic manner, it would be of the utmost importance to construct an impounding reservoir somewhere above Poulaphuca Fall so as to impound these numerous sudden rushes of storm water, and thus equalise the flow of the river, reducing at the same time the violence of the floods.

The remarkable flood in November last caused the back water to rise above the level of the weir at Island Bridge, where there is a fall of something like 14 feet under ordinary circumstances, and no doubt all the mills along the lower part of the river were stopped by excess of water on this occasion. The level of the Liffey just above the fall at Poulaphuca is over 500 feet above the sea, so that a great quantity of energy would be stored in the proposed reservoir per acre covered.

I regret that I have no information about the Boyne and Blackwater except as regards the fall at Slane, which appears to be from 4½ to 5 feet, and to point out that Lough Ramor, situated at an elevation of 277 feet at the head of the Blackwater, should be valuable as a storage basin for these rivers. Neither have I been able to obtain much information as to the rivers in the southern part of the country, with which I am not very familiar.

Many small powers exist scattered through the country which are not of enough importance to be considered here, and which have no neighbouring powers with which they could be agglomerated for purposes of transmission. These small powers may, however, in the future, be utilised electrically with great advantage for the operation of creameries and for working threshing machines, and for other agricultural operations as well as for electric lighting, inasmuch as small steam engines are notoriously extravagant in fuel, and fuel itself is very costly in some districts, owing to the heavy expense of railway carriage and cartage.

In conclusion, I must apologise for the numerous instances in which I have been unable to give definite information in regard to the subject, the data having been mostly collected during holiday time and not with a view to publication of any kind. My object in bringing the subject forward is rather to draw attention to the fact that water-power of considerable value exists in the country, and that the time has arrived when a careful survey of this power should be made as a first step towards its employment for industrial purposes.

Professor W. F. Barrett (*Chairman*) expressed the thanks of the meeting to the author, and stated that in his opinion this paper was one of the most important contributions to this subject since the publication of Sir Robert Kane's work on the "Industrial Resources of Ireland." He quite agreed with the author as to the need of more careful observation and collection of data relative to the rainfall and available water-power in different parts of Ireland. Might it not be possible for the county surveyors, or the highly-trained officers of the Geological Survey Prof. Barrett.

Prof. Barrett.

Department, to take up this work? the latter furnishing reports as to the aqueous as well as solid surface of the ground, returns that might be of much service in the industrial development of the country.

The author had referred to the difficult question of the use of water-power interfering with salmon fishing; the interests of individuals must, however, be subordinated to the interests of the community, adequate compensation, of course, being given to those whose rights had been interfered with. And on this subject, why should there not be in Dublin a Board of Trade looking after and encouraging the *industrial* aspect of the river question? There exists an able Fishery Board which takes the fishers' view, and one cannot expect this Board to look favourably upon the views of water-power users when such use interferes with fishery rights. One great difficulty in the industrial use of water-power was the irregularity of supply from summer drought and occasionally from winter frost. Hence some form of auxiliary power or of suitable storage must be used. This aspect of the subject had been examined by Mr. Perry, county surveyor of Galway, the able brother of our former distinguished president, who would, he hoped, give them a contribution to this discussion.

Among the great electro-chemical industries which might possibly be carried on with water-power in Ireland there were the Castner-Kellner alkali process, the manufacture of aluminium, the raw material of which—bauxite—is at present exported from Ireland to Scotland to be worked at the Falls of Foyers. Again, graphite, now being made from gas-coke by the electric furnace, might be made from coked Kilkenny coal by electricity derived from Irish water-power. The Bischof process of manufacturing white lead by electrolysis was another new, and might become a great, electrical industry. He longed, however, to see this utilisation of hydro-electric power in small industries throughout our towns as now exists in Switzerland, where, as in Geneva, a great town is both lighted and supplied with motive-power by utilising the flow of the Rhone.

Why should not we in Dublin make use of the available energy in the Vartry water-supply as well as of the water itself? The former we now allow to run to waste at the various pressure-reducing reservoirs; we keep the water and throw away the horse-power that the water gives up. Through the kindness of Mr. Spencer Harty, the city surveyor and engineer, he had been supplied with the following data:—"The average daily consumption of the Vartry water throughout its route is 13 million gallons, which yearly comes to 4,745 million gallons. The level of the water at the Roundwood reservoir is 692 ft. over O. D., and the average level of consumption may be taken as 20 to 80 ft., or, calling it 42 ft., giving 650 ft. of fall." As one gallon of water weighs 10 lbs., we have $13{,}000{,}000 \times 10 \times 650$ as the ft. lbs. of energy in the daily consumption of the Vartry water, or 3,520,000 ft. lbs. of energy per hour, all through the year. As 1 H.P. per hour equals $60 \times 33{,}000$ ft. lbs., this is equivalent to, say, 1,800 H.P. If all the water used were run through water-motors the actual H.P. obtainable would depend on the efficiency of the motor, less the loss of energy through the friction of the pipes; the amount would there-

fore be reduced, say, by one-third, or to 1,200 actual H.P. every moment throughout the year. If this power were sold at £10 per H.P. per annum, it would yield £12,000 a year. But obviously the distributing pressure through the city, which comes from the Stillorgan reservoir, must not be interfered with. Hence, if the energy of the flow into the Stillorgan and other reservoirs were alone used so as not to interfere with the city and suburbs distribution pressure, there would be about two-thirds of the foregoing H.P., or a continuous supply day and night of, say, 800 H.P., divided between the successive pressure-reducing reservoirs. The use of this energy would not interfere with the water supply; it would be practically constant all the year, and round these reservoirs small industrial settlements might spring up which would utilise the power now thrown away. Prof Barrett.

Mr. JAMES DILLON thought this was the most favourable time to take up the subject, which has been before the public for the last forty or more years. From personal knowledge he was able to confirm the author's figures. He thought most good would be done by utilising first existing water-power sites, and then utilising and improving the natural water-power sites on the west coast of Ireland where the rainfall and water-power is greatest, rather than attempting work on the east coast, where the rainfall and summer discharges are lowest. Mr. Dillon.

It was very important that full data should be first obtained, and to be reliable this should extend over a period of at least five years. He thought the author's suggestion ought to be pressed upon the Government departments without delay; observations could be made as suggested by the police practically without any additional expense, since some of the police must be near their barracks (where rain-gauges could be kept) every morning. The available water-power depends partly on the rainfall and partly upon other matters, such as surface, inclinations, and height of falls. One inch of rain will produce great water-power at certain seasons, and in certain localities and not in others. Every case taken up must be carefully and sufficiently studied. He had great faith in the advantages to be derived from dealing with the small, unused existing mill sites and the good undeveloped natural falls of the country.

With regard to storing energy in lakes, he thought the practical solution of the problem would be found in lowering the level of the rivers rather than in raising that of the water in the lakes, storing up to the existing summer and winter levels, and thus avoid the immense compensation that might otherwise be awarded for excessive flooding, &c. He considered peat fuel of good quality might be usefully employed for auxiliary power in districts containing quantities of it. Sir R. Kane dealt generally with the average water-powers only, and therefore he thought it should be pressed upon the Government departments to collect all information relative to the rainfall and natural waterfalls as soon as possible. It was unreasonable to ask people to wait and to incur the expense of providing five years' rain returns before being able to start any useful work, or even to apply for a Government loan for the carrying out of the work.

Mr. C. DAWSON, Comptroller of Rates, offered some observations Mr. Dawson.

Mr. Dawson. upon the industrial question as regards Ireland. At the Exhibition of 1882 it was made clear that there were a great number of manufacturers in Ireland, and now, with respect to the forthcoming Cork Exhibition, there were hundreds of applications for sites from Irish manufacturers, and in many cases the manufactures were unrivalled. He referred to the Bill on water-power introduced a few sessions ago by Mr. T. M. Healy. In this Bill powers were sought to facilitate the use of water-power. A Commission sat upon the matter, and the Bill passed the three readings in the lower House, but was most unfortunately rejected in the Lords. Private rights should not override public requirements. The time had certainly arrived when a careful survey of the water-power available in the country should be made. This had already been done in the Pyrenees and in Switzerland, and by the Government in France. He suggested that such a task for Ireland could not be placed in better hands than in those of the Vice-President of the Board of Agriculture, the Right Hon. Horace Plunkett.

Mr. Dick. Mr. F. J. Dick thought the paper a most valuable one, especially in drawing attention to sites not generally known. He desired to add some figures to those given by the author, as he thought the latter might otherwise be misleading. The maximum discharge of Irish rivers varied greatly. For instance, at Killaloe on the Shannon it was about 0·62, and at Belleek on the Erne about 0·73 cubic feet per acre per minute, off areas of 2½ and 1 million acres respectively; whereas at Stranorlar on the River Finn it was about 8 cubic feet per acre off about 80,000 acres. For small catchments the maximum was very much higher still per acre. Again the minimum summer flow for five months in 1887 at Belleek was about 0·025 cubic feet per acre per minute, while at Killaloe in dry years it fell occasionally as low as about 0·012. As a general rule the minimum flow of a dry year might be taken to be, for catchments of more than say ten square miles, about 0·02. Average summer flow is generally about double the minimum, but on the other hand the minimum of a dry year is sometimes only a half or a third that of another year. As the catchment areas and levels of rivers at any given point can readily be ascertained from the Ordnance Survey maps, a sufficiently close approximation to the power available in summer at a given point can readily be made by means of the foregoing figures, provided that the catchment area is large enough, and assuming that no artificial storage is to be provided. If auxiliary steam power is provided, it is usually of less importance to know the extreme minimum to which a river may occasionally fall for a few days in a dry year, and of more importance to know the probable average summer flow during three or four months of a dry year, and this, as already stated, is about double the minimum, excluding short floods.

Mr. Marshall Harriss. Mr. G. Marshall Harriss did not altogether agree with the remarks of the last speaker. He thought it would be misleading to accept any one figure as applied to all rivers as the average, or minimum, discharge per acre of catchment area when estimating the value of a river for power purposes. He attached practically no importance to particulars of rainfall unless the nature of the catchment area has been carefully studied, and as so many rivers differ in this respect each

one requires separate and independent examination. He endorsed all that was said in the paper as to the great want and importance of such detailed information. From his observations of the Dargle river at Bray and the much larger Barrow at Carlow and Milford, the difficulties of deducing anything reliable from the rainfall had been brought home to him. In Carlow they very often had very heavy and continuous rain and have expected and prepared for a flood and no flood has come; again, after only two days' rain they have had a flood down upon them before they knew where they were. Mr. Marshall Harriss.

In most rivers the tributaries, which are comparatively short, nearly always have, in ordinary rains, discharged their maximum flow before the maximum flow of the main river has arrived, but the rainfall, though not necessarily great, may be, and sometimes is, such that the two maxima occur at the same time, and a great flood is the result in such cases; as the rainfall goes up, the power goes down—at Milford it very soon falls to zero.

He merely referred to this to show, if observations are to be of any value, how carefully they must be made, and if they wished to follow the wave of high water occasioned by any rainfall from the source of any river to its mouth, the question of accuracy in the time of making observations as emphasised by Mr. Dillon must be very strictly observed. He was much interested in all that gentleman had said.

He would have liked more figures as to the capital cost of water-power. It is much more costly to develop a water-power than to lay down a steam plant. On that account he thought there was more immediate hope, if they directed their attention to the utilisation of some of the many water-powers already developed. He suggested difficulties in the proposed method of collecting the power, but the problem would be solved the moment a cheap method of storing electricity became possible, and such was perhaps not far off, as neither weight nor great efficiency would very much matter in a battery for such a purpose.

The question of transmission would remain, and undoubtedly would have to be solved by the use of bare wires carried overhead. At Carlow they had a transmission line five miles long working at from 3,000 to 5,000 volts; the wires were rubber covered, suspended between the poles by shackles and iron suspension wire carried on insulators. The insulation resistance of the bare iron wire is always from 700 to 800 per cent. better than the covered conductor. They had made experiments proving that a pressure of 5,000 volts could be safely carried on the bare wire in all weathers, and if that could be done in such a case, there could be no difficulty in constructing a cheap and safe high-pressure line in this country. He would go so far as to say that a bare-wire line would be much safer to the general public on account of it being less liable to be carried away in storms, &c. One has only to picture a few miles of rubber-covered conductor with its suspension wire and shackle insulators, and to fancy such a line in an exposed position and acted upon by a full gale, to realise the great strains that would be put upon the posts and every part of the tackle. All this is avoided if one has the bare wire.

Mr. Ruddle

Mr. M. RUDDLE said that with reference to the suggestion made by the chairman of obtaining power from the Vartry water, he had gone into the matter somewhat since the last meeting, and from careful investigations made some ten years ago he had come to the conclusion that the utmost available horse-power between the two most favourable points on the pipe-line was seventy-five, and even with that power the cost of conversion and transmission destroyed its value, and if it were desired to use the full head available at Roundwood the cost of the engineering works there added to the cost of the transmission line would be a great drawback to its profitable use. With reference to the author's remarks regarding the limitations imposed by the Board of Trade, he remarked that the Board had recently shown an open mind; it must be remembered in this respect that an overhead line conveying current at very high pressure was something like a railway, and must be fenced at serious expense for the ordinary protection of the public.

As regards water-power generally, many people thought there was more in it than was really the case; in using water-power the main thing saved was the fuel, and this is only about 25 per cent. of the works costs. The capital cost of the turbines would be about the same as for the boilers and engines, and there would be in addition the large capital expenditure on water-works, dams, &c. In Ireland it must be borne in mind that the principal towns are situated on the sea coast, and consequently the cost of bringing coal to them is less than would otherwise be the case. In all cases reliability was an essential; in the Swiss falls, at Zürich Municipal works, there was 12,000 H.P. water and in addition there was 3,000 H.P. in steam; again, at the Oerlikon works there was energy derived from water-power at Hochfelden, twenty-two kilometres off, and there was in addition three times the H.P. in steam, and indeed, in winter steam only was used, owing to ice stopping the water supply. At Schaffhausen, he understood, the mills have large steam reserves, one of 360 H.P., so that even in Switzerland it was found to pay to use steam.

The cost of transmission was always a difficulty. In the Frankfort-Lauffen case the loss in transmission was equal to 25 per cent., and it was found that the cost of the power in Frankfort was five times that at which it could have been generated locally. He believed that at Niagara, while the cost at the turbines was 12s. per H.P. per annum, at Buffalo the cost had increased to £2 12s. per H.P. per annum. He feared that, at any rate in coast towns, the cost of transmission would be prohibitive.

In France, in the mountainous districts where water-power was plentiful, it was not to be found in general use; and most of the use was to be found on the large rivers for corn- and saw-mills. He thought that to deal with the water-power in Ireland the matter should be taken up locally and studied thoroughly. He suggested that the borough and county surveyors could give valuable help in this respect. It was most necessary that *data* should be accumulated first on the spot before any estimate could be made of the value of any water-power, and before it could become commercially valuable some manufacturing use must be found for the power available.

Mr. A. E. PORTE said he disagreed with the statement that there was no coal in Ireland; there are coalfields to be found—in Kilkenny at Castlecomer, in Cork at Millstreet, in Roscommon at Arigna, in Tyrone and Antrim, and no doubt at other places. One seam of the Kilkenny coalfield is known to cover 20,000 acres, and we should hear more of our coalfields in the near future. Mr. Porte.

Regarding the water-powers mentioned, he thought it very desirable that the existing water-powers should first be developed. To start out and make a systematic survey of the whole of Ireland would be too serious an undertaking altogether; apart from the cost it would take years to accomplish.

The utilisation of electrical power in industrial undertakings is a very wide question, and one of the first considerations, in his opinion, was, What power was worth developing? Without wishing to minimise the value of small powers, he thought that 200 H.P. was the least that would pay for its development. To take a case or two, the production of calcium carbide required from 200 to 250 H.P. to be worth working, for the reduction of aluminium a very large current was required, of course at a low voltage, but nevertheless each crucible required, say, 20 H.P., so that a set of ten would absorb 200 H.P. at least.

In engineering work a weld on a 2-inch iron bar required 90 to 100 H.P., and allowing another 100 H.P. for work in the shop, 200 H.P. was soon absorbed.

As pointed out by Mr. Dillon, it was a matter of the very first importance to have the records of droughts, floods, &c., of a particular river (extending over a couple of years at least) before any time or money was expended on it, as the question of capital involved in developing water-powers was very serious; for if steam must be provided as an auxiliary to take the place of water during droughts or floods the water-power must be very favourably situated indeed to be worth developing at all. There might be cases where the dual capital expenditure would pay, but they were few and far between; in fact, a water-power to be really valuable must be absolutely reliable: no necessity for steam as an auxiliary, and situate within easy reach of a railway, canal, or port.

Viewed in this light, it was probable that one could count the really practicable water-powers in Ireland upon the fingers of one hand.

There might be something in Mr. Tatlow's suggestion of using a chain of small water-powers; the idea was very ingenious and original, and in transmitting power between the links of the chain, or indeed anywhere through the country, bare wires should be used; the assumed danger was a bugbear.

A recent case in point where a mill was burned, a client of his transmitted all the power to another mill, a mile or so away, with the result that there was a saving of coals of several hundreds per annum.

Mr. F. J. DICK desired to add a water-power not mentioned in the paper—two sites on the Lower Bann at Portna and Movanagher. These two were remarkable in this respect, that artificial works rendering them available for water-power had already been carried out, and the Mr. Dick.

Mr Dick. sites were now standing unutilised. By an Act of Parliament it was provided that the quantity given might be 20,000 cubic feet per minute. The fall at the first site is 14 feet, and at the second 11 feet; altogether there was available at all times 500 or 600 H.P. The sites were a little away from a railway, and were held by the Board of Public Works.

The question of water-power naturally associated itself with electric light, since the maximum supply of water coincided with the maximum demand for electric light, that is, in the winter.

With reference to the suggested chain of mills, in cases where there was very little power in available sites in summer, if an industry were of such a nature that power was required in the winter, when there was plenty of water, he thought it was quite possible that good results might be had by adopting such a chain.

Mr. Kinsey. Mr. A. T. KINSEY said that at Navan there existed a bakery driven by electrical transmission which had been in use for some years. While it was true the Midland Railway Company (of Ireland) had used the water-power on the Royal Canal mentioned in the paper, it was doubtful whether such a course was altogether beneficial to the Canal, especially in dry weather. He believed one reason for the non-use of small water-powers for electric light was that in small places practically every one was interested in the local gas company. At Athlone the military authorities have for years used steam to pump water into the barracks, and the same applies to water for the town and for the railway company, and as this had been done with the water-power mentioned by the author right on the spot, he could only assume there was some strong reason why the water-power was not available. The woollen mills on the river used steam-power only.

With reference to the use of bare transmission lines, he instanced a case where an important telegraph line had been stopped by a boy breaking an insulator, and thought that this might happen in the case of a high voltage power wire; the Board of Trade might therefore well be cautious in respect of sanctioning bare overhead lines.

Mr Perry. Mr. JAMES PERRY (*communicated*): The subject of Mr. Tatlow's paper is of very great interest, and it is one which will more and more force itself upon our attention. There is too often a suspicion that persons dealing with prospective Irish industries build castles in Spain, raise huge superstructures on insufficient foundations. There is not the slightest good in any kind of over-statement, and there is much to be said in condemnation of it. It is our business as engineers of one speciality and another to put our facts plainly. As Irishmen we desire to see our island prosperous, and we know that if we can present a hopeful scheme which will bear the criticism of men who are outside the glamour of sentiment, we shall be able to get money and give the scheme a fair trial. There is this difficulty, however: it is easier to get money for some big thing than for moderate proposals that I would expect to grow larger from comparatively small beginnings. The most satisfactory water-power is where there is a never-failing source giving a constant supply night and day, and uniform all the year round. We may suppose such a power may be taken from Niagara, and it is only so, even there, because it is not attempted to use all the power which

may be supposed to be available. We can have such a power anywhere if we can afford to be content with the minimum flow of the stream. The first obvious effort of economy is to save the fourteen hours' night flow so as to use it in the ten hours' working-day. Suppose 70 cubic feet a minute on a 10-foot fall gives a horse-power, that means that you would require to store 5,000,000 cubic feet each night if your steady power was 100 brake H.P., and you would then have 240 H.P. available during the working day. But there are further discounts to be taken off this. To store you must do away with some head, and if you store with economy of head it means flooding a very large area. The user of water-power is very much a creature of the circumstances in which he finds himself—6,000,000 cubic feet would cover about 138 acres one foot deep. If this storage is compared with other stores of energy it will be found to be very bulky. The question of storage and expenditure within the twenty-four hours is of very great importance in electric light undertakings; it is a question to which I have given great attention because it is of special importance in our small undertaking at Galway. Water storage is not available for our special benefit, because at Galway a large number of millowners take their power from the common reservoir—Lough Corrib. In this connection I have watched with very great interest the development of storage batteries. I have worked with electric accumulators for over twelve years, and I begin to hope that these expedients will be found to be a practical means of storing energy. My sober estimate of their efficiency is that if the energy you put into them costs you nothing, the energy you get out of them costs, allowing fairly for maintenance and interest on cost of battery, about £10 per horse-power per annum working a ten-hours' day. This is very much better than I have done in the past, but last autumn I put down a new battery, and what I state above is in accordance with the guarantee of a respectable firm of manufacturers and the rate per annum for which they agree to maintain for ten years. A disadvantage of electric storage for manufacturing purposes is that your turbines are working night and day, but on the other hand smaller turbines and machinery, tail races, &c., produce the power. We change our ground very completely when we consider the question of storing flood water in the wet months so as to be able to keep up a uniform power all the year round; the circumstances are rare under which this can be done artificially. Mr. Tatlow has observed the very great volume of flood water in the Galway river as compared with the quantity available for power during the dry months of summer, and it should be remembered this is the overflow from the second largest lake in the three kingdoms. Now the storing of months of energy by damming water in a lake with a ten-foot head outfall is a large operation; the energy would be more compact if it could be put into carbide of calcium, and I think this idea deserves working out. Power for ordinary manufacturing purposes must be always of known reliable amount. Business cannot be carried on at the present day intermittently; it will not do to have to say to the workers: "Oh, owing to ice our power will not work our machinery and 10 per cent. or 20 per cent. of you must go home till the ice melts or till more rain

Mr. Perry.

Mr. Perry. falls." We must have a steady power of known amount available when it is wanted. I have discussed the idea of getting all the available power of twenty-four hours into ten working hours, and again the possibility of equalising the power in the working hours the year round; there is of course the expedient most commonly resorted to, auxiliary power. I have resorted to auxiliary power myself at Galway; I have a small Dowson gas plant and a Crossley engine.

I regret that very great present pressure of work prevents my giving Mr. Tatlow's paper more consideration than I have been able to give it. I am conscious that mere statements of general opinion are of little value, they should be founded on carefully built-up argument, but I may be allowed to say that I see no good reason for the opinion that Ireland is not suitable for manufacturing industry by reason of there being few coal mines in Ireland; for example, Dowson gas has been used to work gas engines in the English coal districts, but Dowson gas is made from Welsh anthracite, and we can get Welsh anthracite at any Irish port at as cheap a price per ton as it can be had for in an English Midland county. Belfast is an important industrial town, yet Belfast imports almost all her raw materials, and all her coals. It is not necessary to limit our ideas of the manufacturing capacity of a place on the coast of Ireland by the estimate of available water-power. Water-power is in certain ways a delightful power; the simplicity of opening a sluice as compared with getting up steam; the complexity of boilers and steam engines or gas engines compared with a turbine appeal to the man who works in both kinds.

I examined the River Erne from Ballyshannon to Beleek, and I was very much struck with the power possibilities of that river. I agree with Mr. Tatlow that the power of Lough Mask is worth careful consideration, and there are other localities in Connemara which deserve examination and estimate of their water-power.

Last summer I was a member of a deputation to which Mr. Horace Plunkett was good enough to give audience; we represented the Association of Water-power Owners, and Mr. J. Perry Goodbody, the President of the Association, attended as principal spokesman on the occasion. Our interview was confidential in so far as our conversation with Mr. Plunkett was concerned, but I am free to say that one of the points I urged was the desirability of a water-power sub-department. There is a controversy of very old standing between persons interested in fisheries and persons using, and interested in, water-powers. Some more economical mode of arranging between the different interests than fighting it out in controversy in Parliament should be found. I confess that my sympathies are not with great schemes for the production of power for no more complex use than the manufacture of chemicals; if such schemes are carried out I shall look upon them as mere temporary uses of the powers. If the powers are set to work in the first instance to manufacture chemicals, better work will no doubt be soon found for them to do.

Mr Tatlow. Mr. TATLOW begged to thank the Chairman and Members for the kind way in which they had received the paper. He thought both the Chairman and Mr. Perry attached too great importance to the effects

of frost on Irish water-powers; they all knew how rarely they got a week's skating in Ireland. The only effect worth considering was the conversion of an open race into a tube by the freezing of the surface, and which would entail an additional loss of head. This might be of importance in long races. As regards the storage of the power during the night, so as to make this available during the working day, the idea of using storage batteries for this purpose had been suggested to him by the owner of a large mill in Tyrone some years ago, and was at that time quite out of the question. Even now, with improved storage batteries, he would not take the responsibility of advising a manufacturer to invest a large amount of capital in storage cells for this purpose, knowing how easily they were ruined by ill-treatment. Very large batteries were in use in connection with traction plants in America, and a large battery, capable of putting out 3,000 amperes at 550 volts, had been erected in Paris. It was, however, quite a different thing to work cells in a lighting or traction station where they were under the care of experts, to using them to store power for factories. Mr. Tatlow.

As regards the cost of such storage, he was of opinion that if the charging current could be regarded as costing nothing, the energy coming out of the battery would cost about 1d. per unit due to interest and depreciation on the cells, and this figure did not differ very much from Mr. Perry's estimate. Wherever the situation was favourable, the possibility of storing power by pumping water into elevated reservoirs should be considered. Such a system was in use at Zürich, where the reservoir had an elevation of 475 feet, and could store 5,000 H.P. hours, and at Geneva where the head was 390 feet, and the storage equal to 4,000 H.P. hours. The latter reservoir was said to have cost £2 4s. per H.P. hour stored, and this compared favourably with storage batteries which would cost at least £6 per H.P. hour stored. The depreciation on a reservoir would be very small as compared with that on batteries. They might remember that it had been proposed to store power for lighting Edinburgh by using refuse destructors to pump into a reservoir on Arthur's Seat; destructors were, however, a very expensive source of power.

Mr. Dillon had referred to the desirability of first using existing mill sites, and the author agreed with this not only because of the saving of capital expenditure, but also because there were as a rule legal rights as regards the use of the water attached to the old mills, whereas the construction of new works involving changes of water level might lead to litigation. Mr. Dillon had referred to the use of producer gas made from peat in gas engines; he believed producer gas made from peat contained more carbonic acid than that made from coke or anthracite, and might possibly not prove satisfactory. He had tried to induce some people who were interested in peat to make experiments in this direction. Mr. Dillon had pointed out that cattle might become entangled or injured by fallen wires if the overhead lines were not strongly constructed. He had found a more serious objection to the falling of wires was that the natives removed them when they fell; it was inadvisable on this account to use wires lighter than No. 10 S.W.G. for transmission. The Board of Trade rules

Mr. Tatlow. provided a factor of safety of 6 for the suspension wires and 12 for the supports of an overhead line, allowing 50 lbs. per square foot for wind pressure, but neglecting the load due to snow. He thought with these precautions the falling of wires should rarely happen.

Mr. Dick had supplied some very important figures with regard to the flow of the rivers at different seasons; he had also drawn attention to two valuable water-powers on the Lower Bann, of which no one seemed to know anything, and the author thought this showed the importance of having some kind of survey made, even if it led only to a tabulation of existing sites. These powers on the Lower Bann being in the vicinity of the beds of Irish alum clay might be used for making aluminium.

As regards the lack of water in summer, if the power was being sold, the supply must be maintained by means of auxiliary plant, but if used by the owners themselves for manufacturing, the output might be reduced or stopped altogether in dry weather. It was unlikely that electro-chemical works could stand the extra capital which would be involved in stand-by plant. Other undertakings, such as distilleries, suspended operations during the summer months, and gasworks employed many more hands in winter than in summer, the men finding other occupations during the summer. In Dublin a number of men worked as hands on yachts in summer and in the gasworks in winter.

As regards power from the Vartry supply he thought the fall was only about 10 feet per mile, and that the most of this head would be used up in the pipes, but of course it depended on the size of the latter. He thought the 10-feet of fall taken by Mr. Perry for the sake of argument, when considering the storage of power in reservoirs, was too low. He looked forward to the time when the users of water-power on the rivers would be more numerous and powerful, and could combine to control the levels of existing lakes; the total falls affected in such cases would be considerable. A range of level of one foot on Lough Arrow should give 300 H.P. for forty days at Ballysadare, which would be a very valuable addition during spells of dry weather.

There did not seem to be anything in the storage of energy in calcium carbide, as it took 11 cwt. of coke to make a ton of carbide, which came out at about 1 lb. of coke to 9 cubic feet of acetylene; this quantity of acetylene would give about 1¼ H.P. hour if worked in a gas engine, whereas the 1 lb. of coke worked in a producer would give up to 1 H.P. hour. If the carbide was made when power was plentiful it would be better to sell it for making illuminating gas, and to buy ordinary fuel with the proceeds.

Mr. Porte had questioned the scarcity of coal in Ireland. The returns showed an output of 125,000 tons per annum, valued at £51,000, which was quite a trifling amount. No doubt the Kilkenny coalfield contained a considerable quantity of coal, but difficulties of transport to the canal or railway had prevented any large output.

The author agreed that 200 H.P. was the least power that could be commercially used to make carbide; it took in fact some 450 H.P. to make one ton per day; both this manufacture and that of aluminium, to which Mr. Porte referred, were furnace processes, and had to be

carried out on a large scale, on account of the losses of heat by radiation and conduction. Processes such as the refining of copper and the production of organic chemicals by oxidation or reduction might be carried on by means of powers of smaller amount. Mr. Tatlow

He found he was wrong in supposing that any surplus water was available from the Royal Canal. As regards Athlone, he could not understand why power could not be obtained there for driving the woollen mills, and for pumping water from the river unless the fall was liable to be affected frequently by the backwater rising.

He would like to see charts made of the principal Irish rivers, showing the flow throughout the year by means of continuous curves. Such curves for the Rhine at Schaffhausen had been published in the Journal (this Journal, 1900, vol. 29, p. 176) for March, 1900, and all particulars of the flow for five years were shown on a small chart covering a single page.

MANCHESTER LOCAL SECTION.

SOME POINTS IN THE EQUIPMENT OF ELECTRIC TRAM CARS.

By W. G. RHODES, M.SC., Member.

(Abstract of Paper read at Meeting of Section, March 18, 1902.)

In considering electric tram cars, no rule can be laid down and no particular tram car, whosoever the maker may be, can be termed the best. One car can be the best for a particular route, but no car can be said to be better than all others under all circumstances.

In choosing the type of car to adopt, the first consideration of the engineer is the nature of the track on which it has to be run. If the most suitable type of car for a particular route is adopted at the outset, endless saving of annoyance and cost of repairs will be effected.

The first point to consider in choice of car is the type and dimensions of truck to adopt, and then the car body must be adapted to suit the truck.

The special features of the track which have to be noticed before selecting the truck are as follows :—

1. The nature of the gradients.
2. The radii of the curves and turnouts.
3. Whether or not the curves occur on gradients or on the level.

If there happen to be no curves of small radius and no gradients worse than 1 in 20 almost any type of truck will prove satisfactory, and the only point to be considered is the nature of the traffic. If great rushes of traffic periodically occur, a few large double-deck cars fitted on maximum traction trucks, together with a majority of single-truck cars, will meet the case, though our experience leads us to prefer a quick service of single-truck cars rather than a somewhat slower service of large ones; small cars are more easily handled and the working expenses are lower. Another objectionable feature of large double-deck cars is the practical impossibility of one conductor collecting the fares when there is a rush of traffic.

If the track contains many gradients of over 1 in 20, single- or double-deck single-truck cars are preferable. In this case it becomes necessary to drive every axle of the truck, and if bogie cars are employed the consequent four-motor equipment makes the ratio of the working expenses to the number of passengers greater than if single-truck cars are used. On account of the fact that each axle must be driven on lines where steep gradients occur, if large bogie cars are necessary to cope with rushes of traffic equal wheel bogies must be adopted.

If sharp curves occur along the track, the wheel base of single trucks must be correspondingly short. If r is the radius in feet of

the sharpest curve on the route, and t the width of the groove of the rail in inches, and b the wheel base in feet, then the greatest admissible value of b is given by

$$b = \sqrt{\frac{2rt}{3}}$$

For example, if $t = 1$ inch, and $r = 75$ feet,

$$b = \sqrt{\frac{2 \times 75}{3}}.$$

$$= 7 \text{ feet, approximately.}$$

The question might be asked as to what would be the sharpest curve that a 6-feet wheel base would take without danger of the car leaving the metals, the width of the groove being $1\frac{1}{8}$ inches. In this case the radius of the curve is given in feet by

$$r = \frac{3b^2}{2t}$$

$$= \frac{3 \times 36}{2 \times 1{\cdot}25}$$

$$= 48 \text{ feet.}$$

If the curve is so sharp that a 5 feet 6 inch wheel base will not take it, then, of course, single trucks are inadmissible, and bogies must be employed.

These conclusions lead to the rejection of single-truck cars if curves of less radii than about 40 feet occur along the track.

While it is probable that at a slow speed the cars might take sharper curves than above indicated, there would be a grinding and wearing action between the flanges and the rails which would diminish the life of both, and it is inadvisable to depart from the rule given above.

I do not wish to give my opinion here about the respective merits of the various trucks on the market, but a few remarks may not be out of place.

The Maximum Traction Truck is satisfactory for speeds up to about twelve miles an hour, and for routes not having gradients of more than 1 in 20. If higher speeds are required or heavier gradients occur, single-truck or equal wheel bogie cars become necessary, because for a given weight on the driving wheels only a certain useful maximum turning couple can be reached, limited by the friction between the driving wheels and the rails. If this couple is exceeded, the only result is to skid the wheels. In the maximum traction truck only part of the weight of the car is on the driving wheels, hence the maximum frictional couple is less than if each axle were driven. There are means provided on maximum traction trucks whereby the proportion of the weight on the driving wheels may be varied. There is, however, a limit to the proportion of the weight

which may be put on the driving wheel caused by the tendency of the pony wheels to leave the rails. This limit is greater the better the track, and imperfections in the track will be detected by the maximum traction truck sooner than by any other type.

The maximum traction truck has often been blamed for repeated derailments, for which a badly-laid track was really responsible.

The next point I shall deal with is Brakes for Electric Tram Cars.

Brakes for Electric Tram Cars.

One of the most important, if not the most important, part of tram-car equipment is the brake. The whole responsibility of ensuring safety and immunity from accidents due to collisions with any obstacle and from runaway cars rests on the brakes.

Brakes may be subdivided into two categories (1) brakes for ordinary service work, and (2) emergency brakes.

Service Brakes.—Brakes for ordinary service work may act either on the wheels or on the rails; that is, they may be either wheel brakes or track brakes. In most cases where the track contains no very heavy gradients a wheel brake is quite sufficient for the purpose, but it may be advisable to employ a track brake for service work on steep inclines. The writer has found that, provided a reliable emergency brake is fitted to the car, the hand-wheel brake is perfectly satisfactory for service work on gradients up to 1 in 10.

The ordinary hand-wheel brake consists of brake-shoes acting simultaneously on the rim of each wheel of the car and operated by chains and pull-rods. The point to which particular care should be taken with these brakes, and, in fact, with all kinds of wheel brakes, is that they should be carefully adjusted so as to operate simultaneously with equal pressure on the wheels. With these brakes an experienced driver can take a car down an incline of 1 in 10 without fear of losing control. Occasionally accidents will happen, such as a rupture of the chain, when an emergency brake should at once be applied.

In order to make the hand-wheel brake as effective as possible it should be kept alive—that is, it should be applied only to such an extent as to avoid skidding of the wheels; this may be secured by easing off the brake slightly at short intervals to ensure that the wheels are not locked.

Electric Brakes.—These are of two kinds; one consists in simply short-circuiting the motors, sometimes through a resistance, so that on going down an incline they act as generators, with the car itself as the motive power. The efficacy of this brake obviously depends upon the revolution of the motor armature, and consequently is ineffective if by the use of a hand-wheel brake skidding of the wheels is produced. A good motor-man can apply the hand-wheel brake so as to produce the maximum braking power on the wheels, so that any other wheel brake appears to be unnecessary.

Disc Brakes.—The disc brake consists of two iron discs, one of which is fixed to the motor and has a coil of wire wrapped round it,

while the other is keyed to the axle. To excite the brake a current is passed through the coils from the motors when running as generators, which are gradually short-circuited through a resistance and the disc-coil. The stationary disc is thus magnetised and attracts the other to form a "keeper," the effect being to tend to prevent the axle from revolving. The braking action is thus seen to be due to two causes—

1. The effect of the motor armatures when run as generators;
2. The magnetic and frictional effect between the two discs.

The braking effect produced by this arrangement is very rapid and powerful, and unless the track is in first-rate condition skidding is sure to result, and the brake to be rendered ineffective. In the author's opinion it is never safe to depend upon a brake of this kind without an auxiliary hand brake. Also from the evidence of those using disc brakes their deterioration is very rapid, and involves constant attention and frequent repairs.

The Mechanical Slipper Brake.—The mechanical slipper brake, though frequently used as an emergency brake, is not at all suited to the purpose, and should be placed in the category of service brakes. It generally consists of a wooden slipper, which brakes on the rail, and which is operated by hand through a combination of levers. This brake may be used for service work on steep gradients, being in action all the time. It should be gently applied at the top of a hill when the car is about to descend, and should be regulated so as to keep the car under control till the bottom of the incline is reached.

Emergency Brakes.—Before describing any brake for emergency purposes, it will be well to inquire into the conditions which such a brake should satisfy.

In an emergency brake it should be possible under all circumstances to apply the brake instantaneously whether on an incline or on the level. The brake should further be operated so simply as to require little or no effort on the part of the driver which would abstract his attention from what is going on. It should further act on the rails, since presumably a wheel brake is already in operation. Many accidents have occurred through not having a brake which will add its effect to wheel brakes already in full operation. Additional wheel brakes are useless, since the maximum braking power on the wheels can be obtained with the hand brake. When this point is reached any additional pressure on the wheels results in skidding, and the only retarding action is the sliding friction between the rails and the wheels. The moment skidding begins the braking action diminishes, and if the car cannot be kept in control by the hand brake, a track brake is essential. It is not often that an experienced driver is not capable of *keeping* his car under control by means of the hand-wheel brake, but it is of frequent occurrence that a car gets out of control before a driver is aware of the fact, due sometimes to carelessness, sometimes to a want of adjustment of the wheel brakes, or to their failure from various causes. In this case it often becomes impossible to *regain* control of the car by any system of wheel brakes whatever. A track brake then becomes invaluable, since its braking action, which may be made very great, is simultaneous with and superimposed upon the

action of the wheel brakes. We are led to the conclusion that an emergency brake must act upon the track itself, and that it should only be used when the wheel brakes are insufficient to control the car or to stop it as quickly as possible in an emergency. The emergency brake must be capable of instantaneous application, otherwise a disaster may have happened before it is brought into action.

Another feature which an emergency brake should possess is that while it can be instantaneously applied with the greatest possible power, its sudden application should not be accompanied by a violent jolting, which would be detrimental to the car itself, and uncomfortably shake the passengers. A great amount of energy has to be dissipated by some means, but it should not be effected by vibrations through the truck and car body.

I now proceed to describe two types of track brake, each of which is capable of immediate application, but differing altogether from each other in principle of action.

The Westinghouse Electro-magnetic Brake.—This brake simultaneously acts on the wheels and axle of the car and on the track. It consists of a horse-shoe electro-magnet suspended by springs from the truck frame, the poles hanging downwards immediately over the track rail. The poles are fitted with detachable brake-shoes which, when the magnet is excited, are drawn down on the rails, and act as any other track brake, excepting that its application does not reduce the grip of the wheels on the rail. By an arrangement of levers connecting the brake electro-magnet with the wheel-brake blocks, the drag of the magnet-shoes on the track is taken up by the pressure of the brake-shoes on the wheel rims. The braking effect on the axle is due to the motors acting as generators, the current from them being used to excite the electro-magnets. It is claimed that the relative magnitudes of the braking effects on the track and on the wheel can be adjusted so as to produce the maximum effect.

While the car is running at a moderate speed the effect of this brake is very powerful, but it diminishes rapidly as the speed decreases, since the magnetic pull between the brake blocks and the rails is proportional to the square of the magnetic induction in the iron of the electro-magnet. It appears therefore, that while this brake can control the speed of the car, it cannot by its exclusive action bring it to a full stop. This is a serious drawback, as occasions sometimes arise when a dead stop must be produced with as little delay as possible. A child might get under a car and be killed by a slow motion, when its life might be saved if the car could be immediately stopped.

Hewitt and Rhodes' Pneumatic Track Brake.—When opening a section of the Oldham Corporation's Electric Tram lines last year, we were compelled to use slipper brakes on account of the heavy gradients on the route. The cars were mounted on maximum traction trucks. On a section previously opened, the cars were fitted with mechanical slipper brakes, but tests showed that the brake took ten or twelve seconds to apply, and then the intensity of its action depended upon the strength of the motor-man. It is plain that a brake requiring ten seconds to apply would be of little value in a great emergency,

where a second's delay might mean loss of life or damage of a less serious nature. Further, the mechanical slipper brake employed could not be fixed to a maximum traction truck. We therefore sought to obtain a track brake which, while being capable of being attached to maximum traction trucks, would more nearly approximate to the conditions which should be satisfied by a brake for emergencies only. The result of this endeavour was our pneumatic track brake, which I proceed to describe.

The air is obtained from an axle-driven compressor which com-

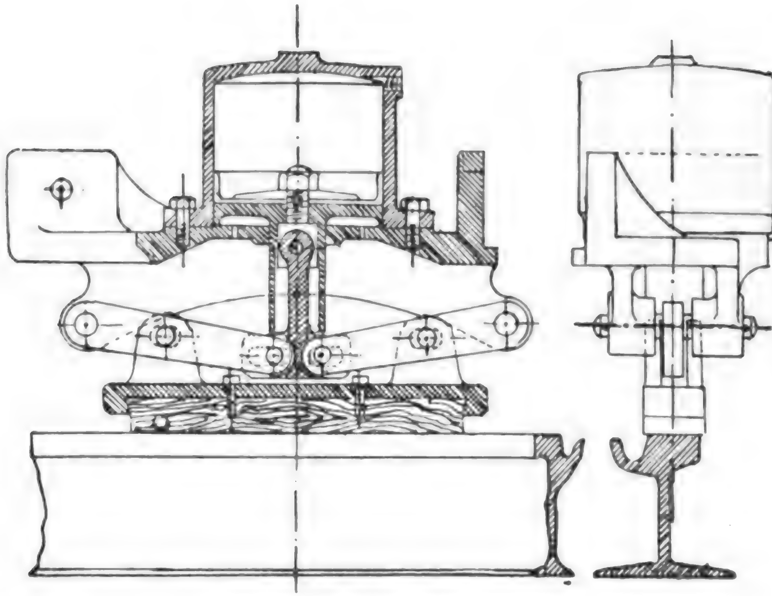


FIG. 1.

municates with a tank or reservoir, which is in its turn connected with the brake cylinders.

The accompanying diagrams represent sections of the brake. An air cylinder is carried on a bracket attached to the truck. The piston of the cylinder is connected by a swinging rod to two levers, which have their fulcra on the bracket. The levers carry the slipper-shoe, on which is fixed a brake block of oak or beech which can easily be removed. Each brake is complete in itself, and can be fixed to any type of truck. To each tram car four brakes are fitted, whether bogie trucks or single trucks are used.

On the single trucks better braking is obtained by using four brakes, as in going down inclines when only two brakes are used a large proportion of the weight of the car is taken by the front wheels instead of by the brakes. The brakes are applied by means of a handle placed

near the hand brake, and above it is a pressure gauge indicating the pressure available for use.

The pneumatic track brake which I have just described has given perfect satisfaction. Very severe tests have been made with it, and the results have been such as to inspire the motor-men with perfect confidence on inclines where, prior to its adoption, one or two mishaps had filled them with apprehension. Every car on the Oldham Tramways is being fitted with a set of these brakes and also with the ordinary hand-wheel brake and the usual electric brake, the last-named being, however, scarcely ever used. Each motor-man is instructed to use the hand-wheel brake for ordinary service work, whether on the level or on gradients, and to apply the track brake only in the cases of emergency.

From careful tests made with this track brake it is found that on a greasy rail a car weighing about 10 tons can be stopped in a distance of 18 yards when running down a gradient of 1 in 16 at a speed of 15 miles an hour; if the rail is in good condition it can, under the same conditions, be stopped in 10 yards, and if care is taken to have the rail well sanded the car can be stopped in a few feet.

Sanding Apparatus.—The figures given above show the great importance of sanding the rails simultaneously with the application of an emergency brake. The usual method of sanding by means of the sand tramp is unsatisfactory, since it requires too much attention and effort on the part of the driver, often a time when he should be able to devote his attention to the control of the car.

I am of opinion that the sanding should be automatically effected on application of the brakes in addition to being capable of being done by the driver at his discretion when the brakes are not on. With automatic simultaneous sanding of the rails on the application of a track brake serious accidents would be of very infrequent occurrence.

Life Guards.—Life guards are subsidiary to brakes, and their only use is to avoid fatal terminations to accidents when the brakes fail or are incapable of pulling up the car in time to avoid running down individuals who happen to get in the way. Up to the present time no satisfactory life guard has been adopted in England. After having experimented with life guards of different descriptions, I am compelled to assert that while some of them would probably save the life of individuals who happen to be knocked down by the car, they would with equal certainty mutilate them.

Some life guards are designed to push an obstacle aside, while others are intended to pick it up. I do not know which method of saving life and of administering severe bodily punishment is the better. To my mind, the position of the guard is wrong. A car travelling at a normal speed can by impact with its buffer seriously injure a person before the guard has any chance of performing its function. In fact, any unfortunate individual who happens to be in the way has to be knocked down before the guard can pick him up or push him aside. The rational position of a life guard is in front of the car, projecting to an extent sufficient to pick up or push aside an obstacle before impact with the car frame is possible.

Some time ago I experimented with a life guard of the hanging gate type. A bag of sand, equal to about the average size of a child of six or seven years of age, was placed in the track and run down by a car at a speed of eight to ten miles an hour. The guard picked up the bag, but in doing so slightly burst it, although the texture of which it was made was extremely strong. It is not altogether conducive to a sense of security if, while being assured that if run down by a tram car the life guard will pick you up, but you may be seriously injured.

Many engineers are of opinion that a plough-shaped guard designed to push an obstacle aside is preferable to those designed to pick it up.

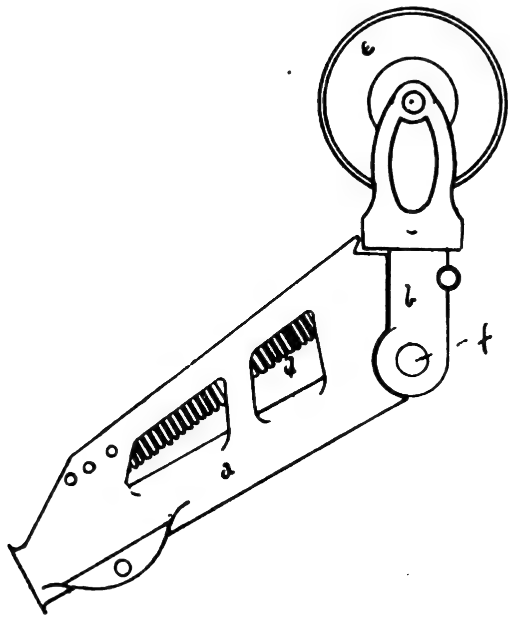


FIG. 2.

In either case there is obviously great risk of serious injury for anybody who is run down by the car. I, for my part, have no preference, since I consider them equally unsatisfactory, and the chief features which would help in arriving at a choice would be the relative costs of the two types.

Other Sources of Danger.—Collisions between electric cars and other vehicles or obstacles which lie in their path are not the only source of danger which has to be avoided. There is also the danger of electric shocks due to falling of overhead wires.

Overhead wires may fall from a variety of causes. The prevention of accident after the wires have fallen does not lie within the scope of this paper. We are now only dealing with the removal of the causes

when such may be dealt with in car equipments. The only part of the car equipment which touches the trolley wire is the trolley wheel.

It frequently happens that the trolley wheel leaves the wire, and not unfrequently becomes entangled with it at crossings and turnouts. The momentum of the car carries it forward and sometimes pulls down the trolley wire. If while the car is in motion the trolley head gets entangled in a crossing, something has to give way. In the majority of trolley heads the whole is of solid construction, and the only yielding portion is the trolley arm. The trolley head which we have adopted at Oldham was designed by Mr. Wilkinson, now manager of the Oldham Tramways, to overcome this difficulty.

In Fig. 2, p. 1177, which depicts this trolley head the pole is fixed into the part *a*. The trolley wheel *e* is fixed by means of a pin to the bracket *c*, which fits on the part *b*, which in its turn is fastened to *a* by means of a pin *f* round which it can rotate. A spring *d* connects *a* and *b* as shown.

If, therefore, the trolley becomes entangled with any wires instead of pulling them, it yields by rotation about the pin *f*.

Car Bodies.—In constructing a car the first consideration should be to ensure the safety of the passengers and the public generally, and the next should be to design it so that the wear and tear may be as small as possible. I have often wondered why and how large double-deck single-truck cars with reverse staircases ever came into vogue. They are not only unsightly, but, as a little consideration will show, are not at all suitable for the majority of tracks. When a car goes round a curve there is always a swinging motion which is felt least in the middle and most at the two ends. Just for the moment applying the principles of rigid dynamics to the case, we have $mk^2 \frac{dw}{dt} =$ sum of moments of impressed forces, where m is the whole mass of the car, k is its radius of gyration, and w the angular velocity of the car about the axis of rotation.

Now suppose that different types of car take the same curve at the same speed so that $\frac{dw}{dt}$ is the same for all at each instant, then mk^2 is proportional to the sum of the moments of the impressed forces.

Now let us suppose that the cars have all the same mass, then k^2 is proportional to the sum of the moments of the impressed forces. From this we draw the following conclusions :—

The internal stress and strains in the car body and truck are proportional to the moments of the impressed forces, and therefore to the square of the radius of gyration. To reduce these internal strains it is necessary therefore to keep the radius of gyration of the car about its axis of rotation as small as possible.

In cars of the double-deck-reverse-staircase type every endeavour is made to load the ends of the car as much as possible, so that the car has to be much more substantially constructed than would otherwise be necessary, or else the life of the car is seriously affected. Seats are placed on the top deck over the guard and driver, and these places are in rushes of traffic crowded with passengers standing on the top. The

wrench on the bolts which fasten the body of the car to the truck when the car goes round a curve is very great, and not only that, but passengers standing at the ends of the top deck are in danger of being thrown off by the lurch.

The reverse staircase is claimed to have special advantages not only in providing extra seating capacity on the top deck, but also in being safer for passengers ascending and descending the stairs. It is an open question whether the extra seating capacity provided on the top deck is not more than balanced by the additional wear and tear consequent upon the straining of the car due to the load being brought up to the ends. Also the unsightly hogging so apparent in the old horse cars is becoming apparent in some electric cars which are heavily loaded at the ends.

Before concluding my paper, I wish to make a few general remarks on the equipment of electric cars.

It often happens that, quite apart from other considerations, the various items in the equipment of cars are settled on the question of cost only. Nothing more fatal to the welfare of an undertaking could be imagined. Not only does it result in constant repairs and increased depreciation, but the safety of the public is greatly endangered, and it would be well to remember that a few serious accidents with their consequent trail of cases for compensation will very soon more than make up for the amount saved in the initial cost of the equipment. It is a penny wise and pound foolish policy which can only lead to financial failure and general disrepute. These remarks are not only applicable to car equipments, but to the whole of a tramway system. The only safe course is to make the best possible job at the outset, and thus avoid a continual and increasingly large demand for repairs.

BIRMINGHAM LOCAL SECTION.

TESTS ON THE NERNST LAMP.

By R. P. HULSE, Bowen Scholar, Birmingham University.

(Communicated by Dr. D. K. Morris.)

Paper read at Meeting of the Section, March 19th, 1902.

It has been known for a long time that certain materials which insulate at ordinary temperatures will conduct fairly well when strongly heated; and this principle has been employed in connection with the electric furnace, but it was not until lately made use of successfully for the purposes of illumination. About four years ago Dr. Nernst applied this principle in the construction of his lamps and used material for their manufacture very similar to that used in Welsbach mantles. Owing to the fact that the melting point is very high, a much higher temperature can be maintained than with a carbon filament, and a higher-efficiency lamp is the result; and also, the material being non-oxidisable, no vacuum is necessary. The materials used for the illuminating rod require to be heated up in order to start the current flowing; but when once heated the rod conducts and need no longer be heated by external means.

A great deal of experimenting and improvement has been necessary to bring the Nernst lamp to its present state of perfection, but the "1902 Model" now being put on the market appears to be a fairly satisfactory article; and it is this lamp which forms the subject of the tests described in this paper.

These tests comprise the measurement on a direct-current circuit of life, candle-power and watts under the following conditions :—

Continuous run at normal pressure.
Continuous run at a pressure above normal.
Continuous run at a pressure below normal.
Continuous run with constant current.
Continuous run with constant watts expended in rod.
Test with varying volts (increasing till burner is destroyed).
Resistance tests on the iron regulating resistance.
Heating effect of coil.

In each case 100-watt 110-volt "burners" were employed.

The candle power of the lamps was ascertained by comparison with standard Ediswan glow lamps standardised by the makers, using an ordinary grease-spot photometer. This photometer was not inverted, but the sub-standard which was employed for taking the actual measurements was itself standardised by comparison with the actual

standard lamp placed on the same side of the photometer as the Nernst lamp had been.

All parts of the photometer bench and apparatus directly exposed to the light that could possibly have affected results by reflection, were painted a dead black, the resulting surface being almost absolutely non-reflecting. To enable more than one lamp to be tested at the same time, and also to avoid shaking the lamps when moving them, four wooden vanes were fixed to a hollow central stem which was pivoted vertically so that four lamps could be hung in the four compartments and any one lamp tested by simply turning this frame round till that lamp was in front. All light from the other lamps was excluded by screens placed round this compartment and at the sides. To allow for ventilation and cooling of lamp by air currents the globes were hung a short distance from the side, the top and bottom of the frame being left open. All the lamps tested were protected by globes and the results obtained from a ground-glass globe reduced to the clear-globe standard for comparison. The candle-power was taken in the horizontal plane with the filament always vertical.[1]

The current supplied to each lamp was measured by a millivoltmeter and strips of known resistance, and the pressure was measured by a Weston moving-coil voltmeter previously calibrated in terms of a standard Clark cell. And the drop across the iron resistance and across the cut-out coil was obtained from another small moving-coil instrument. The necessary corrections were made to the readings given by these instruments to obtain the true values. The pressure on each lamp was adjusted by small carbon cloth rheostats or by stretched wires with sliding contacts, and was brought up, when necessary, to the required value before a reading was taken.

As a battery of accumulators was used to supply the current, a very much more steady pressure was maintained than would have been possible with the mains, the excess volts when charging the battery being cut down by a regulating resistance. The average variation in pressure for any long time was certainly not more than ½-volt, and generally less; and it will be seen later, that since under perfectly steady conditions the lamp itself varies 2 to 3 per cent., sometimes more, a steadier run was hardly required.

The life was in all cases, unless otherwise stated, perfectly continuous, only one break occurring in the circuit during the seven weeks, and that for but a few seconds.

LIFE TESTS.

In every life test made there was a very considerable falling off in candle-power,[2] in the first half-hour amounting to 25 per cent. in the

[1] For information on the distribution of light in Nernst lamps, and on the ratio of horizontal to mean spherical c.p., see Prof. Wedding, *Elektrotechnische Zeitschrift*, August 1, 1901. Other information is given in a Paper by A. J. Wurtz, *Jour. Am. Inst. E. E.*, June, 1901, p. 511.

[2] This initial reduction is characteristic of the Welsbach burner also, and as pointed out by Dr. Fleming in the discussion of Swinburne's Paper in February, 1899 (see *Electrician*, February 10 and 24, 1899), is a property of all oxides used as illuminants.

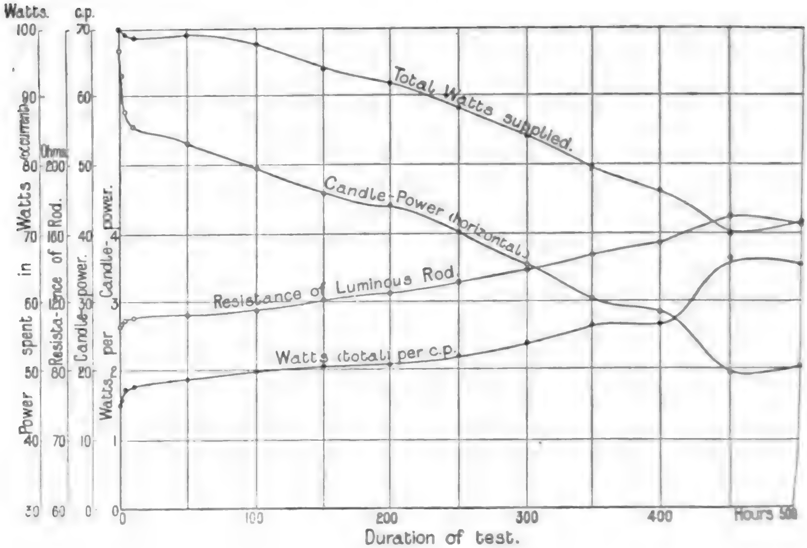


FIG. 1.—Life Tests at Normal Voltage. Average of 3 Tests on 100 Watt 110 Volt Burners.

Pressure in every case: 109·5 Volts. Average Life: 470 Hours.

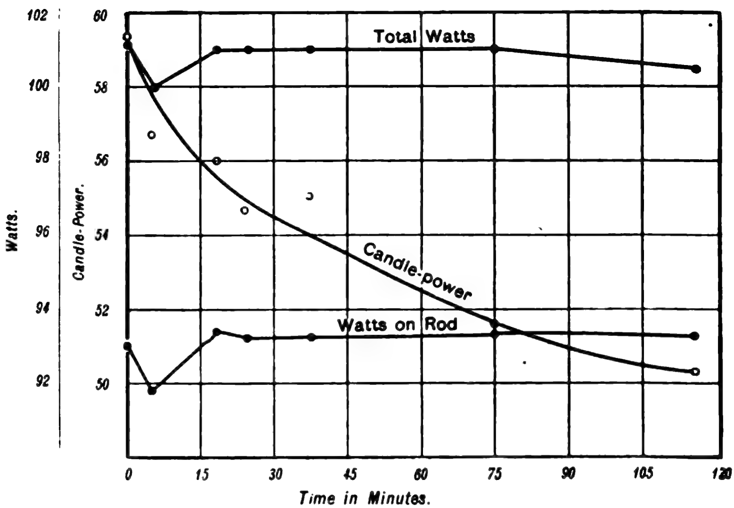


FIG. 2.—Life Test on Nernst Lamp. (109·5 Volts, 100 Watts, 110-Volt Burner). First two hours after lighting.

over-run lamp, but only about 10 per cent. when on normal volts. After this we get a much slower drop until 20 hours is reached, then, as a rule, there was a slight recovery followed by a period in which the variations depended on the conditions under which the lamp was run.

1. *Tests at Normal Voltage.*—Three lamps, each marked 100-watt

110-volts, were tested on 109·5 volts and a mean curves plotted from the three sets of curves obtained. These three were substantially the same, the big decrease (Curve II.) and slight recovery being shown in each; and, after this, a steady diminution of candle-power until 400 hours, the efficiency during this part also diminishing (see Curve I.). After 400 hours there was another sudden drop, and then the state of the rod seemed to change, for there was a slight rise in efficiency and candle-power up to the point where the burner broke down.

TABLE I.

Life Tests on Normal Volts (109·5).

Mean values from curves representing three separate tests.

Hours after Start.	Current. Amps.	Watts Absorbed. Total in Lamp.	Watts Absorbed. Per Cent. on rod only.	Candle Power.	Watts per C.P. Total.	Watts per C.P. Rod only.	Resistance of Rod. Ohms.
0	·917	100·5	88·4	66·8	1·51	1·33	105·6
1	·913	100	89·1	62·9	1·59	1·42	106·8
3	·906	99·2	90·1	57·6	1·72	1·55	108·9
10	·903	98·8	91·2	55·4	1·79	1·63	110·7
50	·904	99·1	92·7	52·9	1·87	1·74	112·2
100	·892	97·7	94·0	49·4	1·98	1·86	115·2
150	·858	94·0	95·1	45·7	2·06	1·96	121·2
200	·836	91·6	95·7	43·9	2·09	2·00	125·2
250	·803	88·0	96·1	40·0	2·20	2·11	131·0
300	·766	83·9	96·7	35·4	2·37	2·29	138·2
350	·724	79·3	97·3	30·1	2·64	2·57	147·0
400	·692	75·8	97·7	28·5	2·66	2·60	154·5
450	·637	69·8	98·2	19·4	3·61	3·54	168·8
500	·653	71·5	98·0	20·4	3·51	3·44	164·2

The lives of the three lamps were 509, 490, and 425 hours respectively, the average being 473 hours. The cause of destruction in each case was the breakage of the platinum contact at the positive end of the rod. This may have been due to the deterioration of contact and consequent local heating.

Length of Efficient Life ("*smashing point.*")—It will be seen that towards the end of the life the efficiency is seriously decreased, the lamp being ultimately no more efficient than an ordinary glow-lamp.

In 1885 Ayrton[1] showed graphically how to find the most economical voltage at which to run a lamp; and later[2] he described how, at a given voltage, with lamps whose economy decreases with age, there is a point at which it will pay best to discard the lamp. This point is known as the "smashing" point. In 1898 Carter[3] gave a construction

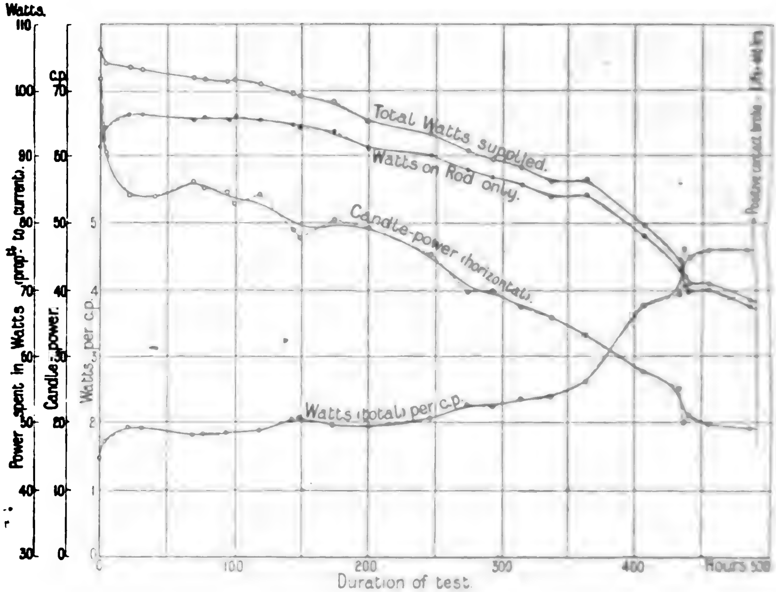


FIG. 3.—Test No. 5. Constant Pressure (109·5 Volts, 100 Watts, 110-Volt Burner).

by which this point could be deduced. A more direct way based on this method is the following :—

Express by a curve the relation for the lamp (at the pressure under consideration) which exists between the cost of energy expended and candle-power-hours obtained, the latter being plotted vertically. From the common zero, set backwards horizontally the cost of the refill for the lamp.[4] A tangent from the point so obtained to the curve gives the point at which the C.P. hours will bear the greatest ratio to the total expenditure; and it is at this point that it will best pay to get a new burner.

[1] See *Electrician*, March 7, 1885. [2] *Electrician*, September 29, 1893.
[3] *Electrical Review*, August 19, 1898.
[4] To this should be added any increase in rate of depreciation of the iron resistance due to using a new burner; and subtracted any allowance which may be obtainable for the platinum heating coil in the discarded one.

Such a curve (No. IV.) has been obtained from Table I., and from it the following figures have been taken:—

Length of run (hours)	...	100	200	300	400	500
Units consumed ...	...	9·88	19·31	28·12	36·09	43·28
C.P.-hours obtained	...	5280	9890	13880	16970	19170

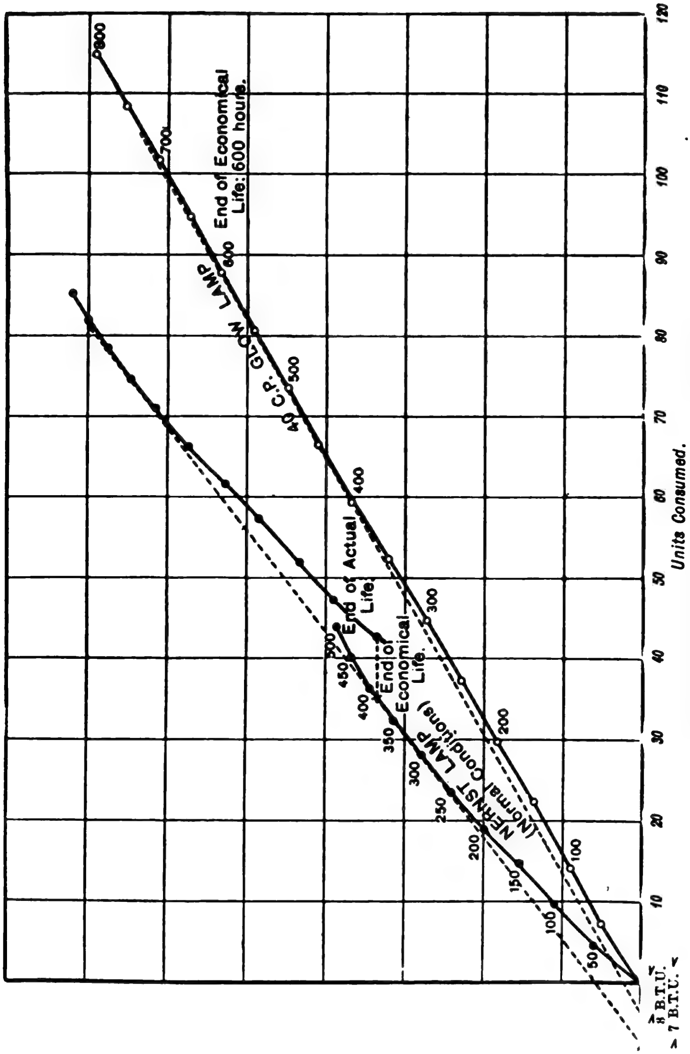


FIG 4.—Construction for finding the Duration of most Economical Life.

Assumptions as to Cost of Renewals are as follows: Nernst Lamp, 7 B.T.U. = 1 new burner; Glow Lamp, 3 B.T.U. = 1 new lamp.

Assuming the cost per unit to be 6d., and that of the burner, fitting, and depreciation of lamp and resistance as 3s., it is found by this method that it will pay to get a new burner at 350 hours; total cost being up to that point 19s.; candle-power hours = 15,500 or ·0147d. per C.P. hour.

Under the very best conditions, with power at 6d. per unit, a glow lamp will cost over ·02d. per C.P. hour.

The relatively short life of the Nernst lamp (about 450 hours) is probably not disadvantageous since it prevents the use of the lamp under uneconomical conditions after the proper "smashing" point has been reached. The natural life of the burner is very near that at which it will best pay to replace it as calculated above. This is very far from being the case with most glow lamps.

2. *Over-run Test.*—This test shows not only that over-running is detrimental to the life of the lamp, but also that it does not result in any considerable gain in efficiency such as occurs when an ordinary glow lamp is similarly over-run.

The iron resistance tends to protect the burner from excessive pressure, and the Nernst lamp is in this way less sensitive to increased pressure than the glow lamp. But when the current in the rod is appreciably increased over the normal, the joints on the rod fail owing to the high temperature; quite a number of small particles of the paste used to cement the joint at the positive end being found at the bottom of the globe at the end of the test.

TABLE II. (See Curves V.)

LIFE TEST ON CONSTANT PRESSURE (OVER-RUN 116·5 VOLTS).

Hours after start.	Total Watts Supplied.	Candle-power.	Watts per C.P.	
			Total.	Rod only.
0	125	94·5	1·32	1·10
½	123	71·5	1·72	1·42
2	117	62·0	1·89	1·58
5	110	52·3	2·10	1·82
15	108·5	52·3	2·08	1·81
50	108·5	53·9	2·02	1·79
100	110·9	52·6	2·11	1·88
150	110·2	61·0	1·84	1·65
200	108·7	58·8	1·85	1·70

The percentage of energy absorbed in the iron resistance is greater than it is with lamps tested on normal volts, but the watts per candle on the rod are a very little less. The behaviour of the rod was somewhat uncertain, and it appeared that the lamp was on the point of failure some time before it actually broke down. The life was very

short—only 220 hours—and failure was again due to breakage of joint at the positive end.

The rod had the same appearance at the end of its life as one run for much longer on normal volts, but there was a heavier black deposit on the porcelain base.

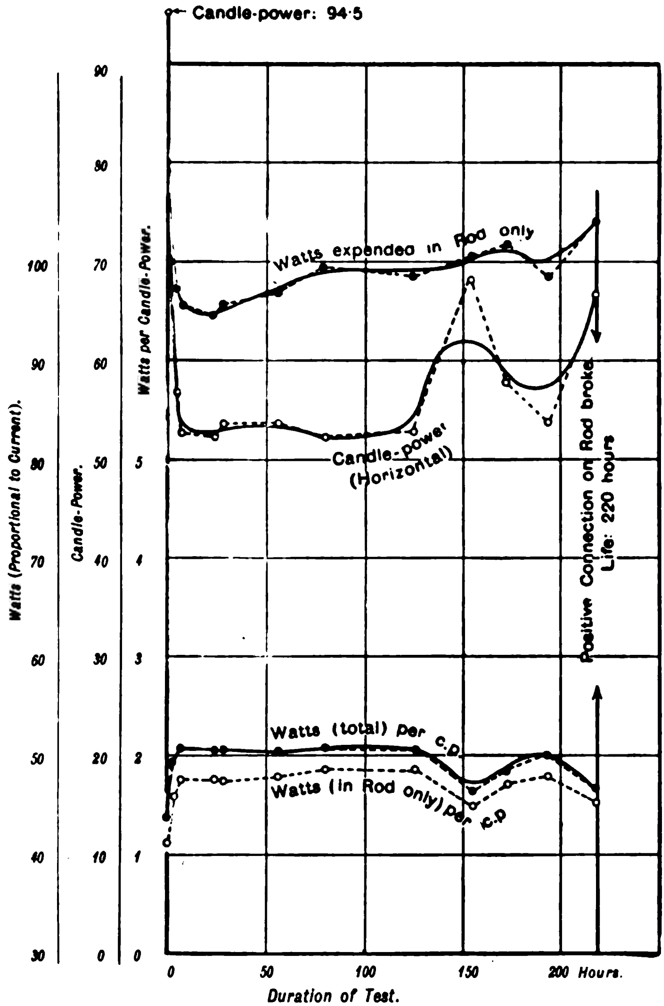


FIG. 5.—Life Test (over-run) at 116·5 volts (100 watts, 110-volt burner); No. 4.

3. *Under-run Test.*—A Long life (1,306 hours) and a very great drop in candle-power are the chief characteristics of this test. At no time did the candle-power remain at all constant, as previously was the case,

but it decreased continually throughout the whole life of the lamp, the efficiency falling off in the same way; and towards the end the luminous rod lacked that brilliancy and whiteness which usually characterise the Nernst lamp.

The difference between the watts expended on the rod and the total watts supplied to lamp is in this case very small, owing to the small drop on the iron resistance.

TABLE III. (See Curves VI.)

LIFE TEST ON CONSTANT PRESSURE (UNDER-RUN, VOLTS 105·8).

Hours after Start.	Total Watts Supplied to Lamp.	Candle-power.	Watts per Candle.	
			Total.	On Rod only.
0	99·5	84·2	1·19	1·11
1	96·9	68·2	1·42	1·35
3	95·9	63·0	1·52	1·433
10	93·5	60·9	1·53	1·45
50	88·9	43·0	2·06	1·99
100	86·8	38·1	2·28	2·21
200	83·6	33·9	2·46	2·42
400	73·4	24	3·06	2·99
600	66·2	19·0	3·48	3·42
900	57·6	11·2	5·14	5·06
1,200	53·0	8·7	6·10	6·00

4. *Test with Constant Current.*—The most interesting test of the series is probably that in which constant current is maintained. Under ordinary conditions the current falls off to a large extent and the burner is then no longer run at its best efficiency, the decrease in candle-power being also objectionable and detrimental to the reputation of the lamp. But with constant current, the candle-power, after its first drop, which is characteristic of every case, remains constant until that point is reached where, under normal conditions, the candle-power would have fallen off very rapidly, and here, instead of a drop, the candle-power *increases* for a short time, until the lamp burns itself out (Curve VII.).

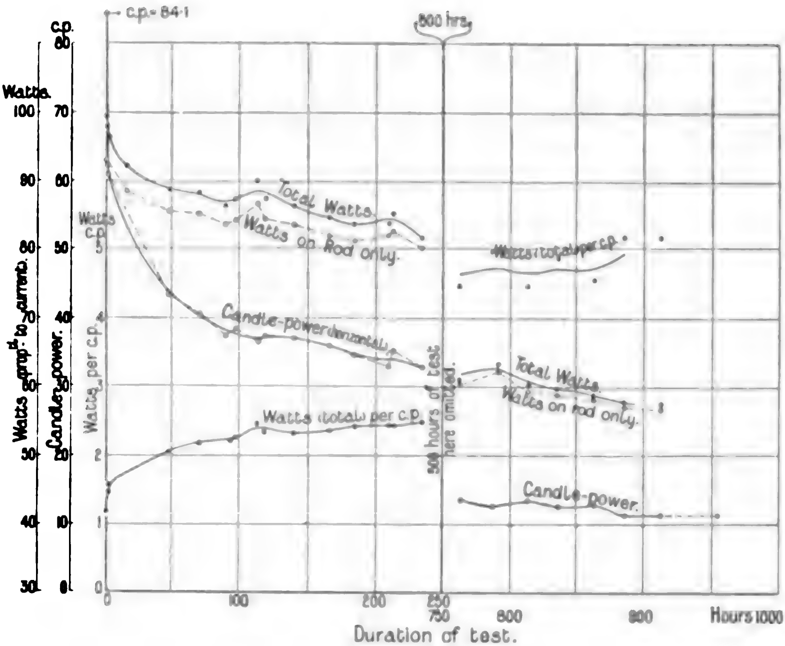


FIG. 6.—Life Test (under-run) at 105·8 volts (100 watts, 110-volt burner); No. 7.

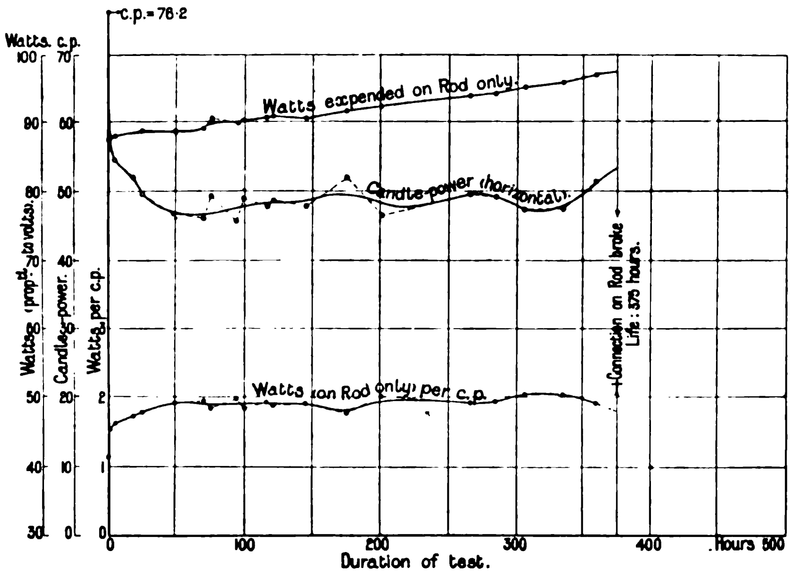


FIG. 7.—Life Test at Constant Current (0·89 amps., 100 watts, 110-volt burner); No. 10.

TABLE IV.

Life Test on Constant Current (·89 amp.).

Hours after Start.	Watts (on Rod only).	Candle Power.	Watts per Candle (Rod only).	Resistance of Rod.
				Ohms.
0	87·3	76·1	1·15	110·1
1	87·8	57·0	1·54	110·7
3	87·8	55·0	1·60	110·9
10	88·0	52·2	1·69	111·1
50	88·7	46·8	1·90	112·0
100	90·0	47·4	1·90	113·7
150	90·5	48·1	1·88	114·0
200	92·1	47·2	1·95	116·4
250	93·1	49·8	1·87	118·4
300	94·7	49·2	1·92	119·7
350	96·6	50·8	1·90	121·9

The life under these conditions was 372 hours. The total power taken is not given, since this depends upon the variable resistance used

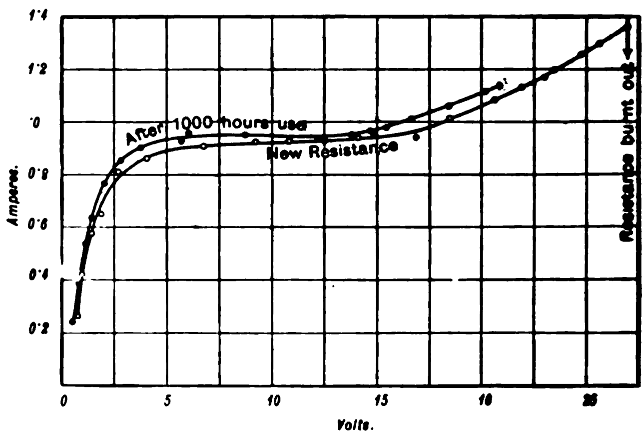


Fig. 8.—Test on Steadying Resistances (Drop across Terminals of the Iron Wire corresponding to Different Currents).

to keep the current constant. By running at constant current the life has been shortened by about 100 hours, but a high efficiency is retained to the end.

5. *Test at Constant Watts.*—A similar test having less practical significance was made by keeping the power absorbed in the rod constant. It was not found practicable to keep the power more than approximately constant. The average efficiency is slightly greater than in tests at constant voltage, while the life is not diminished as in the constant-current test.

LIFE TEST WITH CONSTANT POWER (85·5 WATTS) SUPPLIED TO LUMINOUS ROD.

Hours after Start.	Candle-power.	Watts (on rod only) per c.p.	Resistance of rod ohms.
0	68·7	1·26	107
1	53·5	1·60	114
10	49	1·75	116
100	40·4	2·05	131
200	34·5	2·50	136
300	34	2·48	145
400	32·5	2·58	146

The burner lasted for 445 hours.

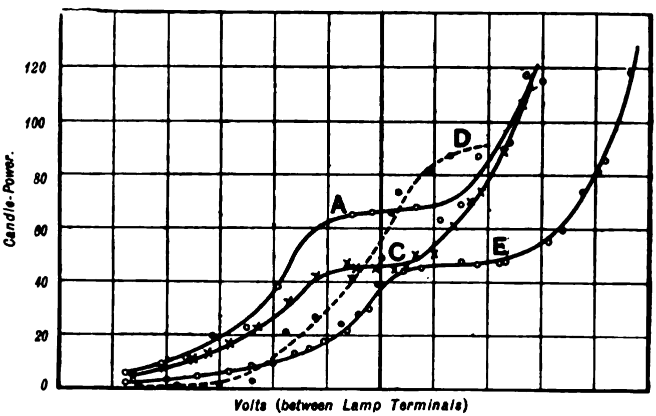


FIG. 9.—Candle-Power Voltage Tests (100 watts, 110-volt burners).

A. New Lamp, Burner No. 2.
C. After 11 hours' use, Burner No. 17.
D. After 212 hours' use, Burner No "A."
E. After 116 hours' use, Burner No. 14.

Tests with Varying Pressure.

C.P.-Voltage Tests. Steadying Resistance.—A most important feature in the lamp is the iron regulating resistance, which consists of a short piece of fine iron wire supported in an exhausted bulb. By comparing the volume of mercury sucked in when opened under mercury to the total volume of the glass bulb, the pressure was found to average 3 inches Hg.

The regulating effect of this resistance was found by increasing the volts and taking readings of candle-power and watts supplied (see Curves VIII. and IX.)

TABLE V.

Regulation Tests on 100-watt 110-volt Lamps at Variable Volts.

Volts.	Candle Power.				
	New.	After 10 hrs. New Iron Resistance.	Ditto. Old Iron Resistance.	After 116 hrs.	After 212 hrs.
90	9·5	7·7	8·5	2·8	0·5
100	35·5	27·5	32·5	9·6	12·5
105	60	42·6	48·0	17·8	25·7
108	63·7	46·0	49·7	26·5	38·5
110	64·5	46·7	50·7	37·0	56·0
112	65·0	48·0	52·7	43·0	74·0
115	66·0	54·0	59·3	46·0	83·5
120	83·0	80·0	94·5	48·0	...
130	...	...	...	81·0	...

TABLE VI.

Variation of Candle Power and Resistance of Rod with the Power absorbed in the Rod only (after Ten Hours' Run).

Watts on Rod.	Candle Power.	Resistance. ohms.
40	5·5	186
60	17·5	145
80	34·0	118
100	53·5	96
120	80	80

Although when the lamp is new there is a remarkable regulating effect for 5 per cent. above and below normal pressure (there being almost no variation in c.p. during this period), yet as the age of the lamp increases this regulation becomes less and less. A different value for the iron resistance it will be seen gives a regulating effect at some other point.

Usually the iron resistance will be destroyed before the lamp in c.p.-voltage tests, especially if the lamp is new; and to burn the rod out a special resistance had to be made, the observations commencing where the others left off.

The candle-power and watts on rod curve (Curve X.) which can

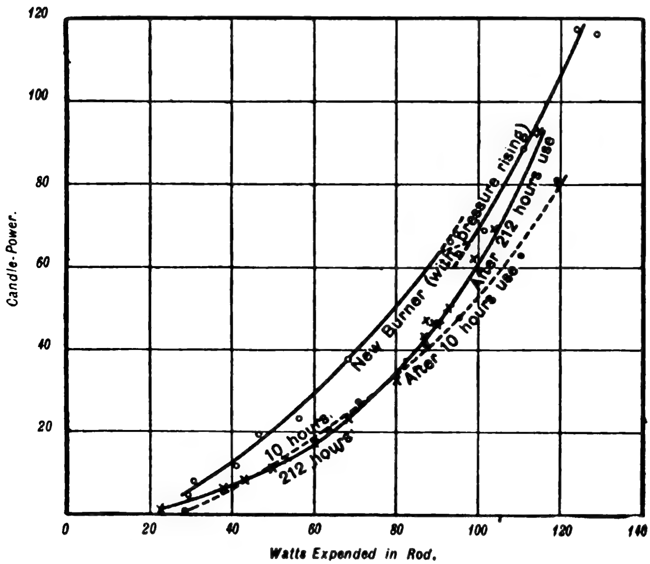


FIG. 10.—Candle-Power Voltage Tests (*continued*). Relation between Candle-Power and Watts Expended in the Luminous Rod.

be plotted from these results show that the candle-power varies as the 2·6th power of the watts expended on the luminous rod. This value was taken from the results given by two old lamps, and satisfies these to within 1 per cent. for a range of from 60 to 100 watts.

Variation of Resistance with Watts Expended. 1. *For Luminous Rod.*—The watts, being the rate of dissipation of energy, are a measure of the temperature, and the resistance varies with the temperature; so that by plotting resistance against the watts expended on the rod, we have a curve (No. XI.) connecting resistance with some power of the temperature, but no absolute values of temperature can be given.

2. *Iron Steadying Resistance.*—A similar curve (No. XII.) can be plotted for the iron resistance, and the similarity between this curve

and that obtained by direct observation at different temperatures is very striking.

The life of the steadying resistance cannot be correctly stated, but

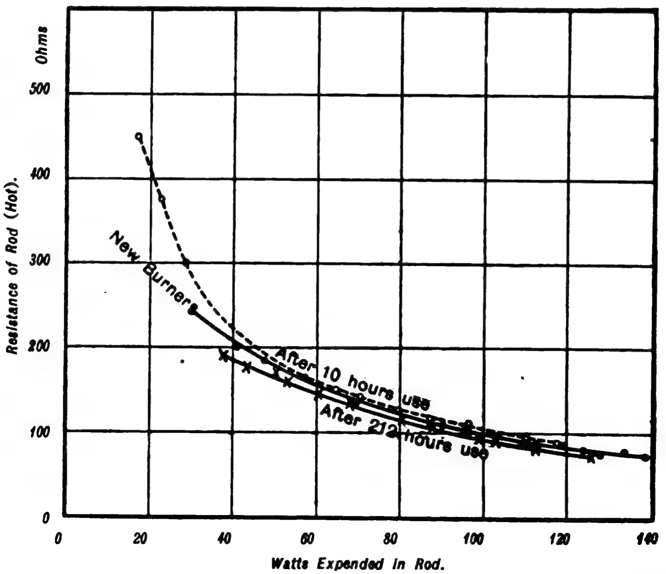


FIG. 11.—Variation of Resistance of Luminous Rod, with Watts absorbed.

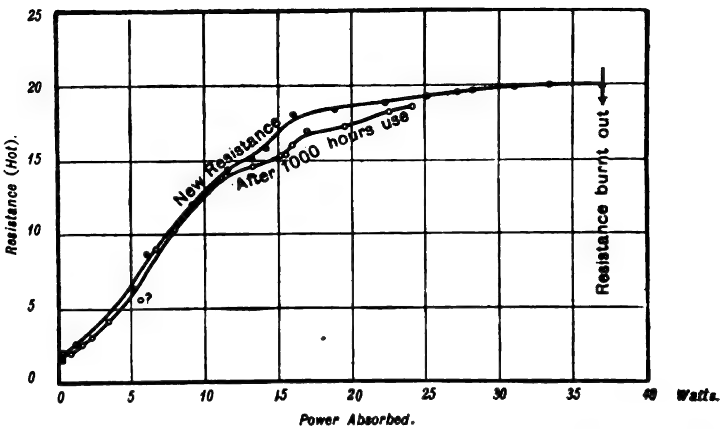


FIG. 12.—Test on Iron Steadying Resistances. Variation of Resistance, with Watts absorbed in Iron Wire.

is very considerable. One used for over 1,000 hours in connection with normal pressure tests has deteriorated very little.

Behaviour of Luminous Rod.—The rod always became crystalline after being in use for a short time, and near the negative end was

blackened, changing through grey to a faint yellow at the positive end. In all cases where life tests have been made there was a white deposit in the glass globe during the first part of the life, and this deposit was especially noticeable in the case of the over-run lamp.

It was observed that at certain times a faint singing or hissing sound may be emitted by the luminous rod. This occurs particularly with new or over-run lamps, and was accompanied with a fluctuation (usually a diminution) of current amounting to about 2 per cent., and an even greater alteration of the power supplied to the rod. It would be very interesting to know how this sound is caused, and whether it is associated with the crystallisation referred to.

These fluctuations of current occur under all conditions of testing, but when they were not great the sound could not be detected. The current sometimes varied 2 or 3 per cent. when the external pressure on the lamp terminals was absolutely steady.

In all the life tests the end of the test was determined by the breaking away of the positive connection at the platinum wire. This is at the lower end of the rod according to the instructions sent with each lamp. Of seventeen burners tested, none but three ended at all prematurely; and these three, curiously enough, were being *under*-run, and, in fact, were undergoing the earlier stages of a regulation test with gradually increasing pressure.

Removal of the globe appears to cool the luminous rod, increasing its resistance and decreasing the current supplied by about 1 per cent.

When once started it is found that a very small current will suffice to heat the rod enough to make it conduct. In this way a burner was observed to give only ·175 candle-power, the current taken being ·193 amps. and pressure on lamp 87·4 volts.

A new luminous rod when normally burning has a specific resistance of about ·7 ohm per centimetre cube (about 100 times that of a carbon filament). The average of three rods which had each run for 450 hours was 1·06 ohms per cm. cube.

Heating Coil and Automatic Switch.—The heating coil, which consists of a clay spiral (arranged around the luminous rod), closely overwound with fine platinum wire, was tested by continuously running it on 110 volts for over 48 hours. No alteration of the heating current occurred during this period, which corresponds to lighting the lamp a very large number of times,—since the lamp only takes about half a minute to light up.

It was also found that the period required to heat the rod to the point of conducting was not sensibly increased after the starting of the lamp 120 times (the rod being allowed to cool between each start); while the diminution in candle-power of the burner due to this frequent heating and cooling was no greater than would have been the case if the lamp had been continuously run for a corresponding time.

The heating coil will plainly last longer than the rod, and it should be possible to use up heating coils by replacing the rod alone.

At no time has the automatic switch failed to act; nor has its contact given any trouble.

In conclusion, there seems to be a wide field for the Nernst lamp where fairly large candle-powers are required and where power is not cheap.

The Nernst lamp will give on the average at least ·48 c.p. per watt expended, as against ·28 c.p. per watt in the case of good glow lamps. The cost of renewals would appear to be not more than three times as much for the Nernst as for the glow lamp, allowing for the shorter life of the former. In a 100-watt Nernst lamp (see curve II.) the total energy used is over 35 units during economical life; and at 4d. a unit this costs 11s. 8d., or, say, not more than fifteen shillings when all expenditure due to renewal of the burner is taken into account.

Thus the Nernst lamp will furnish 1,000 c.p.-hours at a cost of elevenpence; while fifteenpence is the approximate cost of the same amount of illumination from good glow lamps. In this comparative estimate the cost of renewals in each case has been included, the price per unit assumed to be 4d., while the glow lamp has been taken at an average of 3·6 watts per c.p. throughout a life of 700 hours.

If the glow lamp be run for a longer period, or the price of the unit increased, the case will be all the more favourable to the Nernst lamp.

Under-running might pay where power is cheaper owing to the increased life; and this, in spite of the low efficiency towards the end (say after about 800 hours; see Table III.).

Over-running of the lamps, on the other hand, is, as stated above, not economical.

The rapid falling off in the efficiency of the lamp under normal conditions after 200 hours seems to show that after this time it would be better to replace the iron resistance shown by one of a smaller value; and so maintain the candle-power at a steady value throughout the life.

My best thanks are due to the Birmingham University authorities, for the current used in these tests and the use of instruments and apparatus; also to Dr. D. K. Morris for facilitating the carrying out of these tests, and for kind assistance in finishing this paper.

Dr. Morris. Dr. D. K. MORRIS said he thought that the Local Section was to be congratulated upon having a paper on one of the very few novelties that had come upon the electrical market of late in reference to electric lighting—a novelty which promised to enable the electrical light to compete, more or less satisfactorily, with the incandescent gas mantle now so common, and to compete on the score of efficiency. The life tests were of interest as showing clearly they had now a lamp which, though its life was only half that of the ordinary glow-lamp, had a much greater average efficiency throughout its life, giving 50 per cent. more light for the same expenditure of power; and the increased cost of renewals was only a small matter as against this 50 per cent. increase in economy. An interesting observation of Mr. Hulse's was the sound occasionally emitted by the luminous rod. It was a remarkable thing that a mere electrical conductor should give forth a sound, when that conductor was apparently not gaseous. In conclusion, he would like

[1] See *Phil. Mag.*, Sept., 1897.

to know from experienced electrical engineers what, in their opinion, was the average expenditure of watts in an ordinary glow-lamp per candle obtained during its average life, as it was difficult to obtain information about the power absorbed in the glow-lamp under the conditions of ordinary use. Dr. Morris.

Mr. J. C. VAUDREY congratulated Mr. Hulse on his paper, but thought that there was much experimenting to be done and a good deal to be learnt before the lamp which had been described would have the same effect on electric lighting as the incandescent burner had had on gas interests, and he was afraid that the Nernst lamp had not the same advantage over the glow-lamp which the incandescent mantle had over the old type of burner. Reduced to electrical figures, he would put the efficiency of the ordinary incandescent lamp at about 2½ watts per c.p. He failed to see the great commercial advantage which the Nernst lamp possessed over the ordinary glow-lamp, as the end of its efficient life, during which the average watts per candle appeared to be something like 2, seemed to be after 100 or 130 hours; and after 500 hours the watts per c.p. rose to 3·5, averaging which brought the consumption in watts to that of an ordinary glow-lamp which lasted for 700 or 800 hours. When the frequency and cost of renewal were taken into account, he was afraid that the disadvantages would exceed the advantages. Another drawback, he thought, was the fact that the lamp was of 40 or 50 candle-power, whilst the average commercial lamp did not necessarily exceed 16 candle-power. Mr. Vaudrey.

One welcomed the new lamp as a distinct adjunct to our supply systems, and he felt that it might only be a matter of time before the lamp was developed in such a way as to give a much higher efficiency. In any case, it would be a thing to be welcomed when, by its increased efficiency, they could reduce the price of illumination to the general public.

Mr. G. HOOKHAM said that his first feeling and his instinct were that, judging from the experiments and figures given by the reader of the paper, the Nernst was not a practical lamp at present. English engineers liked simplicity. Foreign engineers loved complications, and the Nernst lamp might suit them. But he thought it would be very difficult to persuade English engineers, for the sake of the difference between a shilling and fifteenpence, which was about the amount of saving mentioned in the paper, to sacrifice the beautiful simplicity of the exhausted bulb for the complications of the new lamp. Mr. Hookham.

Mr. A. H. BATE suggested that the hissing sound proceeding from the lamp might be due to the changes in conduction of a current through the heated air surrounding the luminous rod, and not to changes in the rod itself. Many years ago he had made some tests which demonstrated the fact that there was a very distinct leakage-current between a platinum plate and a platinum wire, about $\frac{1}{16}$-inch apart, when heated to bright incandescence, with a potential difference of 100 volts between the two. It was possible that it was a similar discharge through the gas surrounding the luminous rod which caused both the hissing and the variation in the current. Mr. Bate.

Mr. HENRY LEA (Chairman), referring to the detrimental effects of Mr. Lea.

Mr. Lea. overrunning, said he did not think that the glow-lamp was properly appreciated from the point of view of its being used at the voltage for which it was made. It seemed to be inseparable from a large distribution system such as we had in our towns and cities, that the voltage should be anything but constant, and lamps anything but long-lived in consequence. But there were isolated plants with extremely short mains where it was possible to regulate the voltage to within 2 volts on a 220-volt plant, and in such cases it was remarkable to see how the lamps behaved. In one case where 130 glow-lamps were employed, after three years' use it was not found necessary to replace a single lamp. This meant an average life of 2,100 hours, whilst one particular lamp, the owner assured him, had given light for 7,000 hours, and was still in use. It would be more satisfactory if the Nernst lamp showed itself more independent of those variations of pressure which seemed unavoidable in large towns.

Another point which did not appear to be very favourable was that in the Nernst lamp there were three possible causes of breakdown:—(1) the rod might give way; (2) the iron resistance might burn out; (3) the heating coil might fail. There was also a suggestion in one part of the paper that it might be advisable to change the resistance during the life of a burner, which made four things to be attended to during the life of the lamp. If the average life were only 400 hours, it seemed to him that the Nernst lamp would require such an amount of personal attention that the saving in cost would not be considered worth the trouble. Mr. Hulse told them that the Nernst people warned users not to overrun their lamps. It would be very useful if they were to say how to avoid doing so, because they seemed to be entirely at the mercy of the pressure on the street mains. The regulating effect of the iron resistance was remarkable to him; it was remarkable that at a certain part of the curve the volts could be greatly increased without any increase in current, and by arranging the resistance so that this current was the normal working current of the lamp the resistance was made of special value to the rod.

In expressing the indebtedness of the Local Section to Mr. Hulse, the Chairman pointed out that in one case the readings were taken over a run of seven weeks without a break. Their thanks were also due to Dr. Morris for bringing the paper before them, and also to the University authorities for providing facilities for the tests.

Mr. Hulse. Mr. R. P. HULSE, in the reply to the discussion, said that the figures given for the glow-lamp were on the whole such as to make the best possible case for it, and that whereas it absorbed considerably more than 3 watts per candle, the Nernst lamp only required for a life of 400 hours an average of 2·1. It is obviously unfair to take the last figures in the life of the lamp, on account of the rapid decrease in efficiency towards the very end of its life. In the construction given for finding the most economical life, the total cost of replacing the burner, including the trouble of fitting, was allowed for. The types of Nernst lamp now being put on the market certainly would not take the place of small glow-lamps, but rather of the very large glow-lamps and small arcs. The 1902 model has had a vast amount of care and

money expended in its production, and to continue saying that the lamp required perfecting before trying it practically was carrying out a cautious policy which seems typical of English practice. Mr. Hulse.

Mr. Bate's suggestion as to the cause of hissing seemed very probable, but the fact that removing the protecting globe, or even a slight current of air on the rod did not affect the hissing, would tend to disprove such a theory. As Mr. Lea had said, a glow-lamp, run on perfectly steady pressure, would burn for a very long time, but at the end of that time would also be taking a large amount of power per candle-power, 6 watts or over. One of the three causes of failure, viz., the rod breaking, was in reality an advantage, since it prevented the lamp continuing to burn after the end of its economical life; the other two were unlikely to occur. The difference between 11d. and 1s. 3d. represented a reduction of 26 per cent., and this figure would probably be considerably increased in actual practice owing to the favourable figures taken for the glow-lamp. The overrunning which the users of Nernst lamps were warned against was not that due to fluctuation on mains, but rather the deliberate overrunning practised by some people who, by buying a lamp of lower voltage than that of their mains, believed that they obtained more efficient results.

Dr. MORRIS, who was called upon to make any further remarks, said that the merits of the Nernst lamp had hardly been appreciated in the discussion. Mr. Lea, for instance, had criticised the lamp on the score of variation of voltage, shortness of life, and trouble of renewing. They could not vary the volts on the burner. Any fluctuation of the mains was absorbed by the iron resistance, and the rod was practically the same as if the voltage had remained perfectly constant. With regard to shortness of life the question arose, what did the public want? Did they want a certain amount of illumination with a certain number of watts, or were they content with putting in a lamp and continuing to get some sort of light for a very long time irrespective of any other consideration. He had heard of a glow-lamp which burnt for 18,000 hours, but the watts per candle were *not* stated. When emphasis was laid on the trouble of renewing the burner in the Nernst lamp it was fair to remember that the lamp was not made in small sizes like the ordinary glow-lamp. He thought it was the most suitable thing on the market for a large room or for halls of moderate size, and, in criticising it, one should compare it rather with the arc than the glow-lamp. Dr. Morris.

ORIGINAL COMMUNICATION.

NOTES ON THE TEACHING OF ELECTRICAL ENGINEERING IN THE TECHNICAL HIGH SCHOOLS OF CHARLOTTENBURG (BERLIN) AND DARMSTADT.[1] (*July*, 1901.)

By D. K. MORRIS, Associate Member.

The following notes were made on the occasion of the visit of the Institution in 1901. They are presented here at the request of the Editing Committee in approximately the same form as that in which they were originally furnished. The notes cannot give more than a general idea of the conditions of electrical engineering teaching in Germany, since the writer is unacquainted with many other and even more important schools of this subject; as, for example, that at Karlsruhe.

The Diploma course of study extends normally through a period of four years. By special arrangements the course can be covered in three and a half years.

At least half a year, and usually a whole year's previous work in a machine shop is required as a condition of entry to the course.

Students are, on the average, from two to three years older than students of corresponding subjects in England.

Summary of Electrotechnical Course (chief subjects only).

Mathematics.—A sound knowledge of algebra, trigonometry, and elementary co-ordinate geometry is insisted upon in the entrance examination (or whatever examination takes its place). The calculus and differential equations with graphical illustrations are fully taught in the first two years.

Mechanics and Physics.—Thorough courses in mechanics and experimental physics in the first two years. Mathematical theory of electricity in the third year.

Main Lecture Courses.—General and mechanical engineering during the first three years. Electrical engineering in the second, third, and fourth years.

Design and Drawing.—General engineering design in the first two years. Design of electrical machinery and fittings in the third.

Technical Laboratories.—Mechanical engineering during one-half of

[1] These notes were prepared for publication with the Reports of the Sectional Committees on the Institution Visit to Germany, but owing to unavoidable causes they could not be printed with these Reports (this Volume, p. 534).

the third year (Darmstadt), and electrical engineering throughout the third and fourth years.

Other Courses.—The remaining time in the third and fourth years is devoted to the study of languages (usually English and French) and to a number of special subjects as below.

Special Lecture Courses.—Among the subjects for special lecture courses recommended to the more advanced electrical engineering students in Darmstadt during the session 1900–1 were :—

Water-power machinery.
Gas engines.
Machine tools.
Planning of central stations for light and power.
Electric mains and feeders. Wiring.
Electric tramways.
Telegraphy and telephony.
Arc lamps and meters.
Patent laws, etc.

Students are expected to take up three or four of these special subjects.

A prize is offered annually to fourth year students for the best design for some previously specified piece of machinery or electrical installation. In Darmstadt the subject for 1900–1 was a 50-k.w. rotary converter ; to be designed to certain specifications and its characteristics to be worked out fully.

The course of study is remarkable for its length ; for the high standard in non-technical subjects insisted upon on entry, enabling thorough treatment and consistent arrangement of the technical courses ; and also for the opportunities for specialisation which it affords in the last two years, these being almost exclusively devoted to technical subjects. It is noticeable, however, that of the time devoted to work in the technical laboratories, a smaller part than seems desirable is given to purely mechanical engineering, the bulk of the testing work being done on electrical machinery and apparatus.

Owing to the greater scale of the institutions as compared with similar ones in England, the services of several professors and of a large staff are available for the department. Thus, in Darmstadt, the electrotechnical department includes 3 professors and 8 assistants with 3 mechanics. And each professor and assistant will contribute each year one course of special lectures, in addition to routine teaching work.

Another result of the extent of the institutions is that the courses can be multiplied so as to be strictly adapted to each student's needs. Separate courses in physics and mathematics, and also in mechanical and electrical engineering, are held for the exclusive benefit of certain groups of technical students. For instance, in Darmstadt, in addition to the full lecture and laboratory courses in electrical engineering, two shortened courses are held in this subject; one attended by electro-chemists and mechanical engineers, and the other by architects and civil engineers.

Number of Students.—In 1900 there were in the Darmstadt High

School over 1,000 engineering students in all the four years, and of these about one-half were studying electrical engineering, and the rest civil and mechanical engineering.

It may be noted also that of 140 students in technical chemistry about 60 were specialising in electro-chemistry.

Equipment of Electrotechnical Laboratories.

The electrical machinery is of all types (not excepting obsolete patterns, but including many of the most recent designs). It ranges in size from about 100 H.P. (such machines being associated with lighting or power supply) downwards, and includes a large number and variety of the smaller machines—rotary converters, and direct-current, single-phase, and polyphase motors. There is a correspondingly great number and variety of measuring instruments.

All but the largest machines are separately driven and their speed regulated by means of direct-current 100-volt motors coupled with spring or leather couplings. Belt driving from a countershaft is little used. At Charlottenburg, direct electric driving is exclusively used in the main electrotechnical laboratory, and each machine is provided with its own tachometer.

The machinery room is clean, roomy, and well-lighted, and the machines are bolted direct to the tiled floor (Charlottenburg). Ample floor space is provided between the machines.

In Darmstadt, many of the machines were bolted to a cast-iron platform, cross slotted with slide-rail section, and mounted on a concrete bed about 18 inches above the level of the gangway. A hand-worked travelling crane is provided over each bay—*e.g.*, to lift 1 ton with a 20 ft. span. Rails are let into the cement floor to facilitate the movement of machinery when out of reach of the crane.

A uniform speed of motors for conducting tests is ensured by batteries of ample capacity, of which there are two or three (100- to 110-volt), each able to drive at full load two or even three of the larger motor-driven sets, and having a maximum discharge rate of from 20 to 30 k.w.

All the circuits from each machine are brought to an adjacent table provided with terminals (or mercury cups) for any required pressure from the battery, and with an ample set of suitable instruments. Curves of errors (checked every few months) are exhibited near each instrument (Charlottenburg).

The instruments in use are often of a cheap type, but are arranged always so that they can be rapidly checked in position. For this purpose, a pair of terminals connected by permanent cables to a standardising room is to be found close to every group of instruments (Charlottenburg).

High-tension work (transformers and insulation testing) is always included in the course. H.T. circuits are lightly railed in.

The lecture rooms are very completely fitted up for experimental demonstration with lantern and otherwise.

Three large halls are devoted to electrical engineering in the Darmstadt Technical High School. One of these is devoted to the larger machines, a second to small machines of all kinds, and the third is arranged as a museum (see below). Elementary electrical tests are taught in one or two separate laboratories. And the more advanced electrical testing which is not directly connected with the testing of machinery is arranged for in a number of small rooms (five or six students working in each). Each of these rooms is devoted to some special class of work as photometry, insulation tests, etc. This arrangement is possible owing to the large staff.

Gifts to Electrotechnical Laboratories.—In Darmstadt the donations include four motors (one of 13½ H.P., the rest smaller), one 7½ k.w. transformer, several switchboard instruments, meters, and arc lamps. Two well-known firms have presented batteries of 6 and 10 cells respectively and considerable capacity. Two others have sent switchboards with samples of all their up-to-date switching appliances, fuses, automatic devices, etc. The samples are well arranged for exhibit—in action where this is of advantage—and they are in many cases exchanged from time to time with more recent examples of the firm's manufacture as the various exhibits become out of date.

Such samples, together with a great number of other miscellaneous exhibits, traction appliances, etc., are shown in a separate hall unless they are in use as lecture illustrations.

The donors include practically every well-known firm in Germany, and a number of less known local firms.

The Mechanical Engineering Departments of the two High Schools referred to are kept separate from the electrotechnical sections, but are equally well equipped.

Attached to the institution (Charlottenburg) there is a very fully equipped section under the Government for conducting all kinds of mechanical tests—strength of materials of construction; microscopic tests, qualities of cements and concrete (for which a 500-ton testing machine is provided); the testing of papers, cloths, fastness of dyes, etc.; testing of lubricating materials, etc.

For much of this information the writer is indebted to the courtesy of Professors Slaby and Joss of Charlottenburg, and Professor Sengel of Darmstadt.

ORIGINAL COMMUNICATION.

SPARKING IN SWITCHES.

By ALEXANDER RUSSELL, M.A., and CLIFFORD PATERSON.

The general adoption of higher pressures of supply has made the rating of switches for use in direct-current electric-lighting circuits a subject of pressing importance. Different makers seem to adopt widely different ratings for switches of substantially the same size and length of break, with the result that a switch which one manufacturer would consider safe to break ten amperes on a two-hundred volt circuit another would rate at only six amperes at the same pressure. This, in addition to the differing requirements specified in the rules of various supply companies, testifies to the lack of any definite data upon which switches may be designed and standard ratings established.

At present in order to find the capacity of a new switch, tests have to be made on the lines laid down in No. 8 (*h*) of the Institution Rules. This (Edition of 1897) runs as follows :—

"8 (*h*). In order to ascertain that switches comply with the above requirements, samples should be selected from each pattern and size used, and should be tested at an E.M.F. and current 50 per cent. in excess of that which will be used on the circuits for which they are intended."

Now, few manufacturers have got 330-, 345-, and 360-volt circuits on which to test the breaking power of their switches, and it has been the object of the authors by means of experiment to find out the laws which govern the spark lengths when direct-current circuits are broken, and to give curves and formulæ which will enable manufacturers to predict with fair accuracy how their switches will act under varying conditions.

When a direct-current circuit is quickly broken a spark ensues at the point of break. As we increase the current, keeping the voltage constant, the spark gets longer and longer until for a certain value the spark stretches across the whole of the air-gap. If the current be further increased the sparks seem to last a longer time, and begin to pit and roughen the surfaces of the terminals. Finally a point is reached at which a permanent arc is maintained, and the circuit can no longer be broken. It seems advisable, then, to make the air-gap in ordinary switches large enough to prevent the trailing spark bridging it, and the question arises, what is the length of the trailing spark when a given current is broken at a given pressure, and what factor of safety would we have if it almost bridged the air-gap.

In order to answer this question we first made experiments to find out how the length of the trailing spark depends on the current and the pressure when a direct-current non-inductive circuit is broken. To do this a very simple piece of apparatus was employed in series

with glow-lamps and other non-inductive resistances. A carefully-machined bar of metal about 12 ins. long by $\frac{3}{4}$ in. × $1\frac{1}{4}$ in. section was arranged to slide over two copper terminals of the same section as the bar, and having a gap of four inches between them. On pulling back this sliding bar the circuit was broken between one of its ends and the fixed copper terminal. The length of the resulting spark was determined by means of a sighting level directed against a scale at the back of the switch, and having a spider line in it parallel to the graduations on the scale. By this device it was found easy to measure the spark

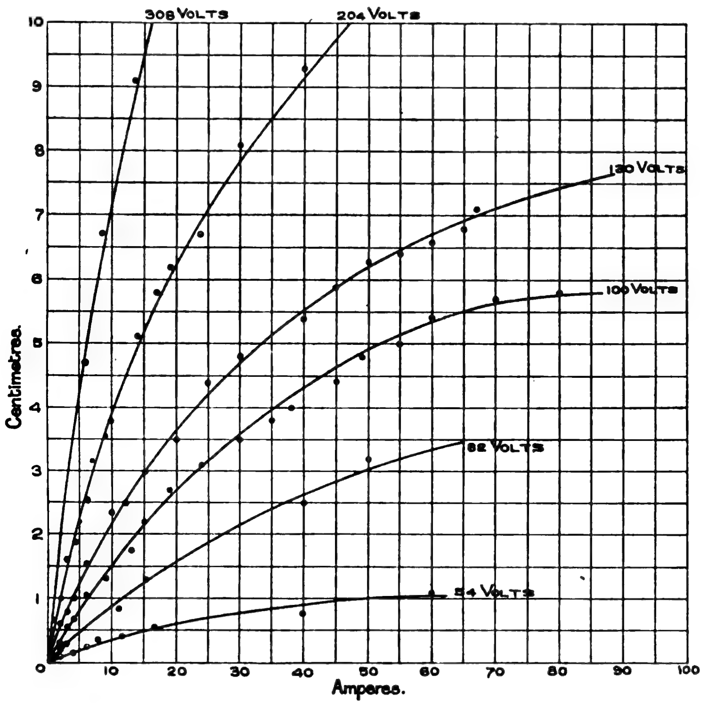


FIG. 1.—Length of Trailing Spark at Constant Voltage. Single Break.

length with considerable accuracy. Experiments were made to determine the following points.

How the trailing spark varies—

(1) With the current when the pressure is constant.
(2) With the pressure when the current is constant.
(3) With the shape of the terminals.
(4) With the speed of the break.
(5) With the number of breaks in the circuit.

(1) *Change of Current when the Pressure is kept Constant.*

The Curves in Fig. 1 show how the length of the trailing spark varies with the current at pressures of 54, 82, 100, 130, 204, and 308 volts

respectively. It will be seen from the curves that a given increase in the current causes a definite percentage increase in the length of the spark whatever the voltage of the circuit may have been. This percentage increase, however, continually diminishes as the currents become greater. We deduce that for all ordinary voltages when the current is increased 50 per cent.,[1] the increase in the length of the trailing spark is given by the following table :—

Range.	Increase in the Length of the Trailing Spark for a 50 per cent. Increase of the Current.
Between 0 and 5 amperes	50 per cent.
" 5 " 10 "	40 " "
" 10 " 30 "	30 " "
" 30 " 60 "	25 " "

The above table has been made as simple as possible as we are not aiming at minute accuracy, but are merely giving approximate rules. It proves that for small currents the increase in the length of the spark is proportional to the increase of the current, but for large currents the spark-length increases more slowly than the current. The similarity between the curves shown in Fig. 1 and the curves showing the rise of current in an inductive circuit is striking, and exponential equations can easily be found for them.

(2) *Change of Pressure, the Current being maintained Constant.*

The curves shown in Figs. 2 and 3 illustrate the effect on the length of the trailing spark of increasing the voltage when the current is maintained constant; Fig. 2 gives the length for a single-break, and Fig. 3 for a double-break switch. It will be seen that for a single break above 80 volts, and for a double break above 160 volts, the curves are practically straight lines. The equations are therefore of the form—

$$\lambda = a\,(V - b)$$

where λ is the length of the spark, V the pressure, and a and b are constants. Hence if λ' be the length of the spark when the pressure is increased 50 per cent., the current remaining constant, then—

$$\lambda' = a\,(1{\cdot}5\,V - b).$$

Hence the fractional increase in spark length—

$$= \frac{\lambda' - \lambda}{\lambda}$$

$$= 0{\cdot}5 + \frac{b}{2\,(V - b)}. \qquad \qquad (1)$$

[1] We choose 50 per cent. increase as this is the increase specified in the Institution Rules (1897).

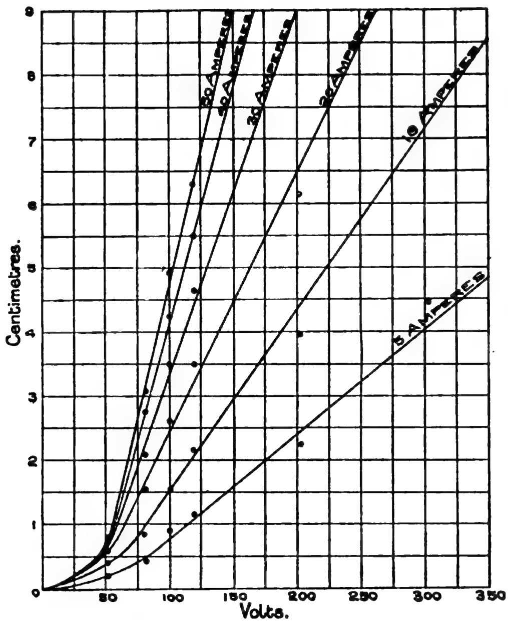


FIG. 2.—Length of Trailing Spark at Constant Current. Single Break.

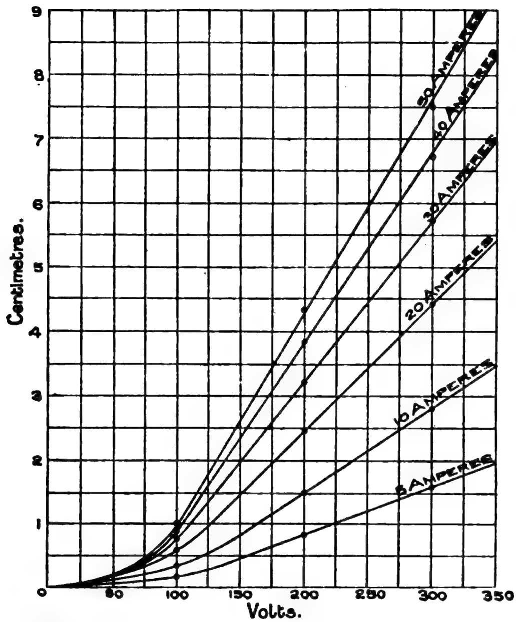


FIG. 3.—Length of Trailing Spark at Constant Current. Double Break.

This equation shows that increasing the voltage 50 per cent. always increases the length of the trailing spark more than 50 per cent., and that the smaller the voltage the greater is this percentage increase. To illustrate the relative values of *a* and *b* we have found equations giving the lengths in centimetres of the trailing sparks at various currents for a single break.

Current in Amperes.	Spark Length (λ) in Centimetres in Terms of the Voltage V.
2	$\lambda = 0{\cdot}006\ (V - 45)$
4	$\lambda = 0{\cdot}012\ (V - 42)$
5	$\lambda = 0{\cdot}014\ (V - 40)$
10	$\lambda = 0{\cdot}0234\ (V - 35)$
20	$\lambda = 0{\cdot}034\ (V - 20)$
30	$\lambda = 0{\cdot}041\ (V - 13)$
40	$\lambda = 0{\cdot}048\ (V - 11)$

These equations show that "*a*" increases and "*b*" diminishes as the current increases. Hence from (1) $\frac{\lambda'}{\lambda}$ diminishes when either the current or the voltage is increased.

The following table calculated from (1) gives the numerical value of $\frac{\lambda' - \lambda}{\lambda}$ at various pressures when the current is maintained constant.

Amperes.	Fractional Increase in Spark Length due to a 50 per cent. Increase of Voltage $= \frac{\lambda' - \lambda}{\lambda}$		
	100 Volts.	200 Volts.	300 Volts.
2	0·9	0·6	0·6
4	0·9	0·6	0·6
5	0·8	0·6	0·6
10	0·8	0·6	0·6
20	0·6	0·6	0·6
30	0·6	0·5	0·5
40	0·6	0·5	0·5

(3) *Effect of the Shape of the Terminals.*

It was found that the length of the trailing spark was practically constant for a given voltage and a given current. The maximum

increase in the length of the trailing spark, due to a change in the shape of the terminals, was about 10 per cent. and occurred when they were sharply pointed. When the sliding contact piece broke the circuit along two straight edges the spark usually occurred at one or other of the extremities of the edges.

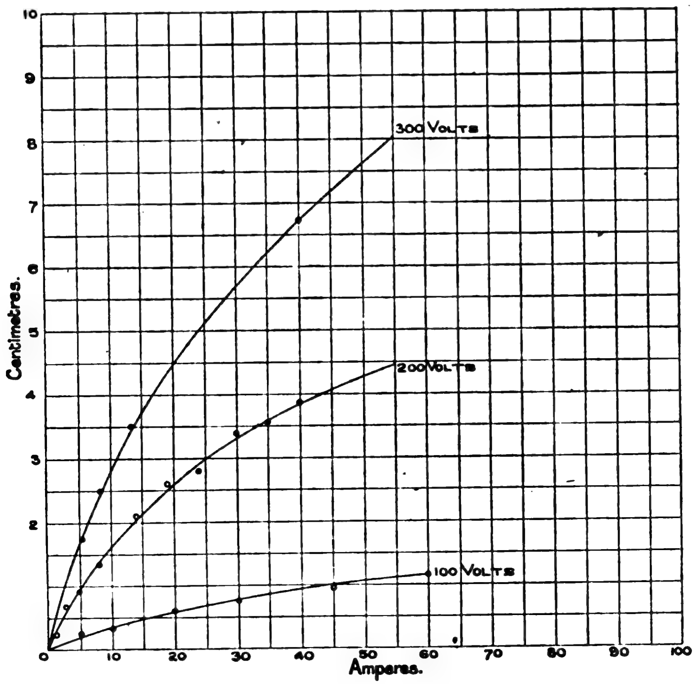


FIG. 4.—Length of Trailing Spark at Constant Voltage. Double Break.

(4) *The Speed of Break.*

At the speeds of break equal to and greater than those usually employed in commercial switches for lighting circuits, the length of the trailing spark is practically independent of the rate at which the circuit is broken. When, however, the speed is decreased below a certain limit, the shape of the spark alters, becoming broader and shorter. As the damage done to the terminals depends on the duration of the spark, it is important that the rocker be brought beyond the limiting length of the spark as quickly as possible.

(5) *The Effect of a Multiple Break.*

As nearly all commercial switches are of the double-break type, it is necessary to consider how the length of the spark is affected when two or more breaks occur simultaneously in a circuit. It is ordinarily thought that by doubling the break the spark-length is halved, but this is not correct. For instance, in a 100-volt circuit the effect of doubling the break is to reduce the length of the spark over four times, and in a 200-volt circuit it is diminished 2·7 times.

The curves in Fig. 4 show how the length of the spark varies with the current for pressures of 300, 200, and 100 volts respectively when the circuit is broken simultaneously in two places. By comparison with Fig. 1 it will be seen that its effect on the spark is equivalent to halving the voltage. For instance, with a given current the spark-length for a double-break at 300, 200, and 100 volts is equal to that for a single-break at 150, 100, and 50 volts respectively. Hence the curves shown in Fig. 1 give the lengths of the sparks for a double-break in circuits up to 600 volts. If three simultaneous breaks were used it would be safe to assume that the spark would be of the same length as on a circuit with a single-break and one-third the pressure.

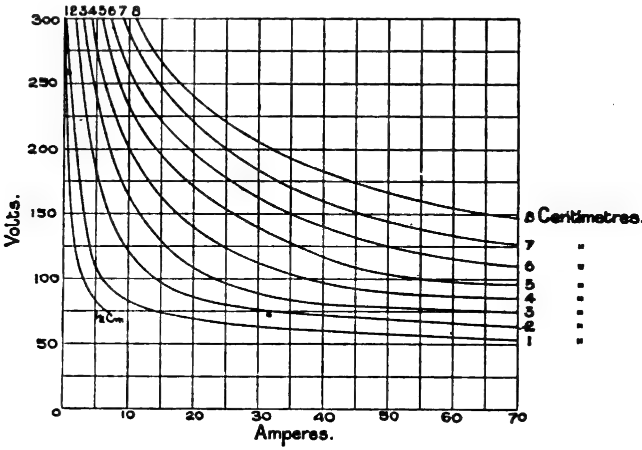


FIG. 5.—Constant Length of Spark Curves. Single Break.

It has been shown above in (1) how to calculate the increased length of the spark for a given increment of current, and in (2) how it alters when the pressure is increased. It is useful to know how it alters when both the current and the pressure vary. For this purpose the volt-ampere curves for sparks of given length have been drawn (Figs. 5 and 6). They show what must be the relation between the voltage and the current in order to obtain a spark of constant length for a single- and double-break switch respectively. The crowding of the curves together at high voltages is very noticeable. For example, 3·6 kilowatts at 150 volts gives a 5-centimetre trailing spark, but half this power will give the same length of spark at 300 volts. The shade of the curves shown in Figs. 5 and 6 is very similar to that of the curves whose equations are—

$$V^2 C = \text{constant}$$

where V is the voltage and C is the current.

Arcing.

In what precedes very little has been said about the minimum distance at which an arc can be maintained between metal terminals. As this fixes an absolute minimum to the breadth of the air-gap and is the point at which the factor of safety is unity, it has a direct bearing

on the design and rating of switches. The authors have therefore made a few rough experiments in order to ascertain the relation of the arcing to the sparking distance between copper terminals. The results are given in the following table :—

	Current in Amperes.	Single Break.		Double Break.	
		Maximum Length of Permanent Arc in Centimetres.	Length of Spark in Centimetres.	Maximum Length of Permanent Arc in Centimetres.	Length of Spark in Centimetres.
100-volt Circuit	5	0·1	0·8		
	15	0·5	2·2	0·06	0·48
	22	0·8	2·9	0·07	0·6
200-volt Circuit	5	1·0	2·2	0·4	0·8
	11	1·2	4·2	0·7	1·65
	18	1·5	5·9	0·8	2·5
300-volt Circuit	3·5	1·2	3·4	0·7	1·2
	6	1·4	5·1	1·0	1·9
	11	1·5	8·0	1·2	3·0
	21	2·2	11·5	1·4	4·5

The above figures show that if switches were designed with an air-gap equal to the length of the trailing spark of the maximum current which they have to break at the normal pressure, then they would have a "factor of safety" ranging from a little less than 2 in small switches to 3 or 4 in large switches. By "factor of safety" is meant the ratio of the actual length of the air-gap to the maximum length at which an arc could be maintained between the contacts at the normal current and pressure. When we say that the factor of safety is 2, we do not mean that the switch can only break double the current, but that the air-gap is double that across which a permanent arc can be maintained. For example, suppose that each of the air-gaps in a 200-volt switch was 0·8 of a centimetre, then if it were rated at 5 amperes the factor of safety would be 2, but it could break 15 amperes at 200 volts although probably the contact pieces would be slightly damaged in the process.

With the data given above, the question of the factor of safety in switches may now be discussed, and it will be interesting to consider one or two of the systems of rating now in vogue with the object of finding out what factor of safety they allow.

The Institution rule says that a switch must be tested with a current

and voltage 50 per cent. in excess of the normal. Let λ be the length of the trailing spark at V volts and C amperes, and let λ' be its length at 1·5 V volts and 1·5 C amperes. Then from Fig. 5 we get the following

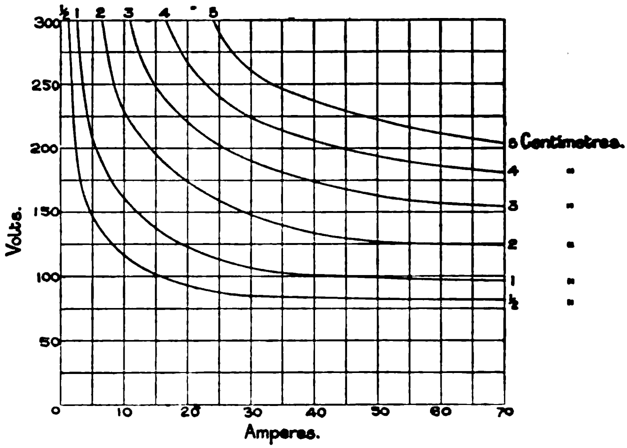


FIG. 6.—Constant Length of Spark Curves. Double Break.

table showing how the trailing spark lengthens with a 50 per cent. increase in current and voltage.

Current in Amperes.	$\frac{\lambda'}{\lambda}$ at 100 Volts.	$\frac{\lambda'}{\lambda}$ at 200 Volts.
1	3·1	3·1
2	3·0	
3	3·0	2·7
4	2·8	2·7
5	2·7	2·7
6	2·7	2·6
7	2·6	2·5
8	2·5	2·5
9	2·5	2·5
10	2·5	2·5
20	2·1	
30	1·9	
40	1·9	

The above ratios are for single breaks at 100 volts and 200 volts respectively. From what we have shown above, however, they also give the values of the ratios for double breaks at 200 volts and 400 volts respectively.

Now the Institution rule simply says that a switch must be tested with a 50 per cent. increase in the current and voltage, without specifying the conditions that it must fulfil under the test. This allows, therefore, of two interpretations. If it is meant that the switch is not to arc, then a 5-ampere switch at 200 volts should just fail to arc when it breaks 7·5 amperes at 300 volts. This would allow a length of about 1·1 centimetres, assuming a double break. The maximum distance at which an arc can be maintained with a current of 5 amperes at 200 volts. is 0·4 centimetre, so that the switch has a factor of safety of 2·8. If, however, a larger switch be considered, say one for 11 amperes at 200 volts, it will be found that the factor of safety has dropped to 1·9. The authors have shown elsewhere that it is advisable rather to increase than to decrease the factor of safety as the current becomes greater.

Another interpretation of the rule is that the trailing spark is not to bridge the gap with the 50 per cent. increase of current and pressure. For example, the length of the air-gaps in a 5-ampere 200-volt double break switch with copper contact pieces would have to be 2·2 centimetres since this is the length of the trailing spark for 7·5 amperes at 300 volts with a double break. In this case at the normal pressure the trailing spark would only be allowed to go across about one-third of the air-gap, and the factor of safety would be very large. It seems obvious that air-gaps of this size are unnecessary, and that this is not a fair interpretation of the rule.

The National Board of Fire Underwriters of America give the following rule: all switches "must for constant potential systems, operate successfully at 50 per cent. overload in amperes with 25 per cent. excess voltage under the most severe conditions they are liable to meet with in practice." If λ be the length of the spark at 100 volts and C amperes, and λ' be the length of the spark at 125 volts and 1·5 C amperes, we get the following table for the values of $\frac{\lambda'}{\lambda}$ for a single break. This table also gives the corresponding ratio for 200 volts with a double break.

Current in Amperes	1	2	3	4	5	6	7	8	9	10
$\frac{\lambda'}{\lambda}$	2·6	2·4	2·4	2·2	2·1	2·05	2·0	2·0	2·0	2·0

Now as to "operate successfully" means to break the circuit, it will be found that this rule, like the Institution rule, unduly favours large switches. These switches may operate successfully at the increased

pressure and current and yet spark destructively at the normal current and pressure.

In the rules of the Glasgow Corporation, which seem to have been framed with great care, the following breaks are specified for use on their 250 volt circuit:—

Current in Amperes.	Air-gap in Inches.
0 — 5	0·5
5 — 10	1·0
10 — 25	1·5
25 — 50	2·0
50 — 100	2·5

If we assume a pressure of 260 volts, and that double break switches are used, then from Fig. 1 we find that with copper contact pieces the following currents will give sparks that will bridge the air-gaps:—

Inches.	Currents required to produce this spark.	Glasgow Corporation Rules.
0·5	5 amperes	5 amperes
1·0	12 "	10 "
1·5	21·8 "	25 "
2·0	34·8 "	50 "
2·5	53·5 "	100 "
3·0	83 "	

The above rules allow a factor of safety of about two over the arcing distance; although, in our opinion, this is quite sufficient from a fire risk point of view, yet it is advisable to increase this factor at the larger currents in order to avoid the shortening of the life of a switch due to the pitting and roughening of its terminals.

The following figures give the factor of safety assumed when we choose the maximum current so that its trailing spark just bridges the air-gap. We have defined the factor of safety as the ratio of the breadth of the air-gap to the arcing distance at the maximum current and normal pressure of the switch:—

	Current in Amperes.	Factor of Safety.
At 100 volts	15	8
	22	8·6
At 200 volts	5	2
	11	2·4
	18	3·1
At 300 volts	3·5	1·7
	6	1·9
	11	2·5
	21	3·2

It will be seen, then, that if we fix the size of the air-gap necessary to be such that the trailing spark just bridges it, then from pressures ranging between 200 and 300 volts this allows a factor of safety of about two up to ten amperes, of about three for currents of 20 amperes, and a still greater factor for larger currents. If the trailing spark fails to bridge the air-gap in a small switch at the maximum current, then we think that it will be found satisfactory in practice. We have found that well-designed small switches in which the spark almost bridges the air-gap are much more desirable than the huge porcelain switches with long air-gaps and easily broken covers which are so much in evidence nowadays.

The question of the trailing spark in alternating current circuits is considerably more complex. The length of the spark at the moment of break obviously depends on the phase of the current, and it vanishes so quickly that its measurement is very difficult. Even, however, if the circuit be broken when the instantaneous value of the current is a maximum, the spark causes very little trouble, and so the air-gaps do not need to be nearly so long as with direct currents. Heating and leakage are practically the only things to be guarded against in alternating current switches for lighting circuits.

The question of sparking in inductive circuits is a very interesting one, but as in practice special devices have to be used to get rid of the flaming spark set up it is rather outside the scope of this paper.

The Effect of using Contacts made of other Metals or Alloys.

This opens out a very wide field for experiment. On using steel terminals instead of copper the length of the spark at break was distinctly diminished, especially with large currents. Zinc terminals gave the smallest spark of any we tried. We have not found any metal or

alloy that has reduced the length of the copper spark 50 per cent., and certainly none that has any claim to be called a "non-sparking" metal.

The following are the main points discussed and the conclusions arrived at in this paper :—

(1) The spark at break ought to be taken as a guide to the rating of a switch.

(2) The shape of the terminals does not make much difference to the length of the spark.

(3) The effect of increasing the speed of break above that ordinarily employed is small.

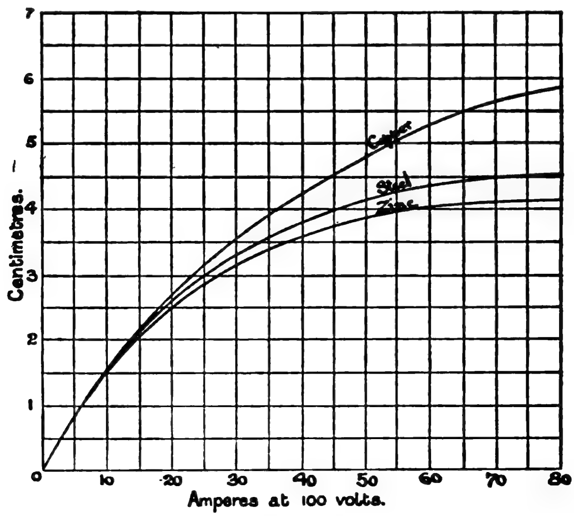


FIG. 7.—Comparative Curves for Copper, Steel, and Zinc, with Varying Currents at Constant Voltage.

(4) The effect of a double break is to make the length of the sparks the same as the length of a spark with the same current at half the voltage.

5) The difference in the length of the spark when copper, steel, or zinc is used, is not great.

(6) For small double-break switches for use on circuits of 200 volts and upwards when the trailing spark just fails to bridge the air-gap the factor of safety is 2.

(7) For double-break switches for large currents under the same circumstances the factor of safety is greater than 2.

(8) The Institution rule as ordinarily interpreted gives a factor of safety of 3 for small switches, and a less factor for larger switches. It is roughly equivalent to the following—

> "In double-break switches up to five amperes the sparks must not stretch farther than about seven-tenths of the air-gap, but for larger switches they may go right across."

(9) The Glasgow Corporation rules give a factor of safety of 2. These rules say exactly what the air-gaps in switches are to be, and must be a great help to manufacturers.

(10) Figs. (1) and (4) given above will enable manufacturers to rate switches with copper contact pieces by simply measuring the air-gaps. For example, suppose that each break is one centimetre. Then from Fig. 4 we see that six amperes gives a spark of 0·95 of a centimetre at 200 volts with a double break. This could also be got from Fig. 1, as this is the length of spark for 6 amperes at 100 volts for a single break. Hence the switch might be rated for 6 amperes at 200 volts, provided it satisfied all the other requirements specified in the Institution rule. In this case we should have a factor of safety of 2. Its present rating by the Institution rule is 4 amperes.

If we have half-inch breaks in the switch and we rate it by the current which gives a spark to bridge this gap at break, then the rating will be as follows:—

(1) At 100 volts — greater than 100 amperes.
(2) At 165 volts — 16 amperes.
(3) At 200 volts — 8 amperes.
(4) At 260 volts — 5 amperes.
(5) At 300 volts — 4 amperes.
(6) At 400 volts — 2·5 amperes.
(7) At 600 volts — 1 ampere.

In conclusion, we would point out that several of the phenomena touched on above require further experimental elucidation; but we publish these results in the hope that others may be tempted to give their experiences or to follow up our experiments.

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NEWCASTLE LOCAL SECTION.

STARTING RESISTANCES.

By ARTHUR E. GOTT, Associate.

(*Abstract of Paper read at Meeting of Section, January 13th, 1902.*)

The object of this paper is to discuss the grading of resistances rather than the mechanical details of switches. A satisfactory starting switch on one load may be a failure on another class of work with the same motor, owing to the greater effect of bad grading. Neglect of good subdivision in starting resistances has produced a demand for slow, screw-type starters by Supply Engineers, who have also issued regulations controlling initial current demands and rate of increase. Satisfactory operation can be obtained only by correct grading.

Starting without Resistance.—This method is admissible for small series motors up to 2 H.P., but it is not advisable for larger sizes; while of shunt motors only the very smallest sizes can be started in this way.

Early Starters.—Many of the earlier starters had a resistance of three to six sections only, and were divided equally. The author gives an example from actual practice, in which the current at the last step was very heavy, causing the motor to give a violent kick.

Modern Starters.—Present-day commercial starters are frequently divided into about three groups of sections of different gauges, such that the product of the resistance, current capacity, and time factor will enable the manufacturer to construct the coils of similar dimensions. Each group is again subdivided equally into two or more sections, and in this way a more or less graded resistance is produced which at the same time lends itself to rapid manufacture. Fig. 1 gives a close approximation to this type on an inert load with the full torque throughout. It is understood in each of these diagrams that contact of the starting lever is maintained on any one step until the current has become normal. In the case of an inert load the peak

may last long enough to blow the fuse or open the circuit breaker, and if they are strengthened the protection to the motor is removed.

Conditions of Load.—The author classifies the various starting conditions to which motors are subjected into a list of five—thus: (1) no load; (2) load increasing with speed; (3) load constant throughout but no inertia; (4) full load and great inertia; (5) inertia so great as to

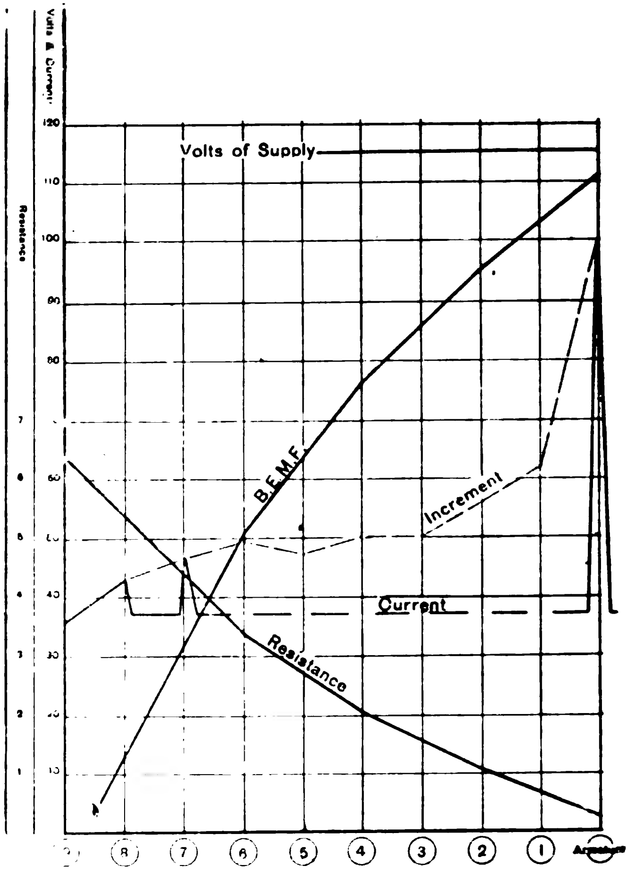


FIG. 1

outweigh all other considerations. An example of the first is in the use of fast and loose pulleys, clutches, etc.; second, ventilating and exhaust fans; third, boiler feed pumps. In the first three classes an average commercial starter will work more or less satisfactorily, particularly with series and compound wound motors. The fourth class is well represented by a web printing machine, to which motors are usually direct-geared. Owing to the amount of energy which must be accumulated in the revolving cylinders before the top speed can be reached,

it is most important that the resistance be so divided that the momentary current in moving the switch from one contact to the next shall not exceed a predetermined percentage. An ammeter placed in circuit will frequently show the peaks as calculated, and with shunt motors the observed increments may even exceed the calculated amounts. With a direct-geared motor it is also important that the predetermined current increment shall not be excessive, as gears may be, and have been, stripped owing to sudden and violent stresses imposed by the starter. The fifth and last condition is one not often met with, and the author ventures to state that no commercial starter as at present manufactured will deal satisfactorily with the case, and enable the motor to start up without undue stress on itself or the starter. This condition exists when the accumulated energy in the driven machine is out of all proportion to the power required to drive that machine. The best, or, rather, the worst, example of this sort which has come under the author's notice was a case of driving a line of exceptionally heavy grindstones, each one of which accumulated 160,000 ft. lbs., but for certain work only required 5 H.P. to run. Each stone therefore required the equivalent torque of 5 H.P. for two minutes to start from rest to full speed in order that the motor should not be overloaded in starting.

Geometrical Division.—Clearly, then, the resistance must be divided so as to limit the increase of current in going from step to step to a definite amount. The correct way is a geometrical subdivision with armature resistance[1] as one extreme and the total resistance as the other extreme. *Certain modifications are required, however, as suggested by considerations of voltage, number of steps available in switch, and conditions of manufacture.* The general rule is stated by the formula

$$a \times f^n = \text{total resistance},$$

when a = armature resistance; f = common factor; and n = number of sections of resistance. As an example, take a motor of 10 H.P. at 230 volts, taking 38 amperes at full load with an armature resistance of ·25 ohm. The current on moving from one step to next is not to exceed 10 amperes. The percentage increase is therefore

$$\frac{10 \times 100}{38} = \text{say, 26 per cent.},$$

and the factor to be employed is therefore 1·26. The resistance, including armature to the end of each section, is therefore : $a \times 1{\cdot}26^1$; $a \times 1{\cdot}26^2$; $a \times 1{\cdot}26^3$; $a \times 1{\cdot}26^4$; $a \times 1{\cdot}26^5$; until $a \times 1{\cdot}26^n$ = total resistance decided upon. The difference between these products = resistance of corresponding sections in starter, the first being $(a \times 1{\cdot}26) - a$. The number of sections required can be found in this way, and in this particular instance 14 sections will give a total resistance of 6·3 ohms—*i.e.*, $(a \times 1{\cdot}26^{14}) = 6{\cdot}3$. The current increment is now uniform throughout, and the motor also runs up to full speed more quickly, but with a smoothness which must be seen to be appreciated. As, however, it is not convenient to manufacture large numbers

[1] In series and compound motors let a = resistance of armature and series field.

of sizes, the number of sections into which the resistance is to be divided may be already fixed by existing patterns, and the common factor (f) must be ascertained to suit the extremes and the number of sections selected. The formula $R = a \times f^n$ must therefore be transposed thus:

$$f^n = \frac{R}{a},$$

$$f = \sqrt[n]{\frac{R}{a}},$$

$$\text{Log} f = \frac{\text{Log R} - \log a}{n}.$$

Having found the factor in this way, the values of resistance, including armature to the end of each section, may be calculated thus: $a f, a f^2, a f^3, \ldots a f^n$. This is a long and tedious process, but there is a very simple method for finding these values mechanically on the slide rule, due to E. A. N. Pochin. (See *Electrician*, vol. xxxix., p. 38, date May 7, 1897) As such a rule is logarithmically divided, all that is necessary is to measure the length in inches between the extremes and divide it into as many equal sections as are required in the resistance. The readings from each section will then give the values of the total resistance, including armature to the end of that section and the differences, of course, give the resistance of each section. This is done by reversing the slide and placing the left end to correspond with an armature resistance and the cursor at the total resistance. The length in inches on the centre scale must now be subdivided equally into the required number of sections and the values read off at each subdivision. It will also be seen that the common factor can be found at once by measuring the subdivision from the unit. This mechanical method has enormous advantages, for, as will be considered further on, several modifications are necessary in order to effect a compromise, and these are performed with an amount of ease altogether impracticable with formulæ.

TABLE A.

Section No.	L to section.	Resistance including armature.	Resistance of section.	—
Armature.	—	·24	—	Further columns may be added for current capacity, time factor, material, gauge, and length required.
1	·8	·348	·108	
2	1·6	·502	·154	
3	2·4	·727	·225	
4	3·2	1·05	·323	
5	4·0	1·52	·47	
6	4·8	2·2	·68	
7	5·6	3·18	·98	
8	6·4	4·6	1·42	
9	7·2	6·63	2·03	
	Total, excluding armature, 6·39 ohms			

We will now take the example shown in Fig. 1 and redivide the resistance by this method, using the same number of sections, and Table A gives the value of each step of resistance. Thus 10 H.P. at 230 volts, total resistance = 6·6 ohms, armature resistance = approximately ·24 ohm. These extremes measure on slide rule 7·2 in.

$$\frac{\text{Extremes}}{\text{Number of sections}} = \text{L } p \text{ section} = \cdot 8 \text{ in.}$$

The increment now is only about 16·5 amperes, or 43 per cent., a great improvement when compared with the 160 per cent. shown by the peak in Fig. 1. Similarly, the author has improved a number of commercial starters simply by taking the connecting wires to new points in the resistance frame, and many have in this way been saved from consignment to the scrap heap. It must be remembered that the current increment is strictly proportional to the current taken by the motor, and if the full current is taken by the motor before it moves and maintained constant throughout, the increment will also be constant throughout. Except on very inert loads the calculated increment is greater than the observed, and therefore a starter designed in this way for the worst load you can have will always be satisfactory for any other load.

Difficulties of Construction.—Now this method of geometrical dividing of motor resistance is not without its disadvantages, and these must be considered before any modification can be made. On referring to Table A, it will be seen that the resistance of the first section to be cut out is 2·03 ohms, and that of the last one next the armature is ·108 ohm. As both of these must go into the same frame, it will be seen that there are serious practical objections. As, however, the first section will only be used for a few seconds, and the last one may allow for one minute starting, the first coil can be much reduced in section, and this is the regular practice. Many resistances are, however, constructed so as to regulate the motor speed down to one-half with the full current, and the one under consideration will therefore require 3·3 ohms to carry the full current continuously. This involves the use of coils of different lengths, and is not conducive to cheap manufacture. Such an objection, however, does not apply to large starters for motors of 50 to 100 H.P., as these are made in much smaller numbers.

Supply Requirements.—The requirements of supply companies, such as limiting the starting current to 10 amperes per section, lead to an impossible number of sections if really complied with.

Initial Current.—Now some manufacturers, so far from complying with the supply requirements, actually make a virtue of the fact that their starters pass one and a half times the full-load current on the first step, and also make a claim that the motor is certain to start. Many such starters have been refused by supply authorities, and eventually discarded for no other reason than this. Other manufacturers have attempted a solution in the manner shown in Figure 2, which represents the first few steps of a resistance designed for 50 amperes at 200 volts, the current increasing in 10-ampere steps up to the full current. The total resistance is, therefore, 20 ohms, and the following

values up to the full current point are as given in the diagram. We will suppose that the motor does not start until full current is passing. On moving switch-arm on to contact A we get 10 amperes, and as there is 10 ohms between 1 and 2, there is a P.D. of 100 volts. On moving on to contact B there is a violent spark, and the current is increased to 20 amperes. The P.D. between the contacts is shown on the diagram, and it will be seen to diminish rapidly towards the armature end. Now consider what happens if the switch-arm is moved back. Violent sparking occurs on leaving the contacts, and this to a pronounced degree in going from B to A. It is here possible, if the contacts do not exceed the arcing limit, to draw and maintain an arc of approximately 50 volts by 10 amperes, with only 5 amperes going round the resistance between A and B, and 150 volts by 15 amperes in the resistance between contact B and motor. Now some manufacturers, instead of using more sections in the resistance, have separated the contacts further to such a distance that the arc cannot be maintained across the gap, and this, being the very reverse of a remedy, has introduced fresh troubles. In the first place, standard slates have been used, and the wider gaps have necessitated fewer sections for more onerous conditions. Secondly, the arcing has not been annulled, and the enamel between the contacts gets burnt off. If the switch is used in a damp and dusty situation—and some must at times be used in such places—the damaged surface of the slate accumulates dirt, with the result that an arc has been known repeatedly to run right across the switch from the first step to the armature end in attempting to start the motor. The effect is, of course, particularly noticeable with high

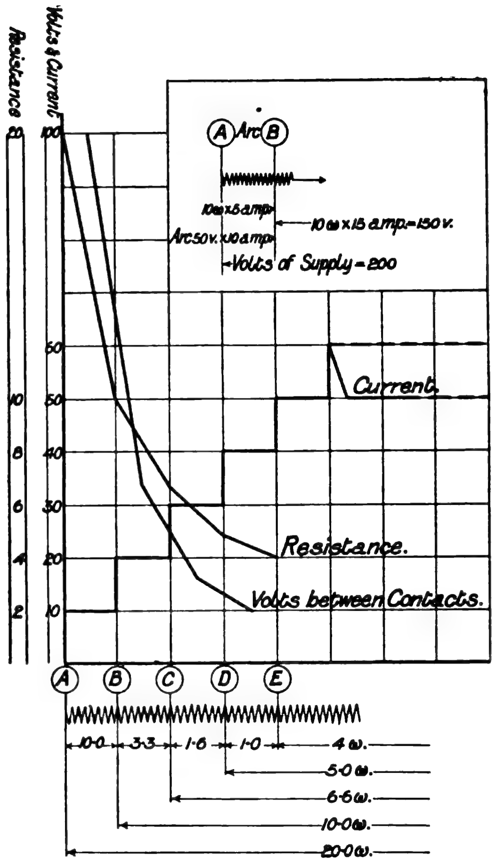


FIG. 2.

voltages of, say, 400 to 600. The obvious remedy is to have more sections in the resistance and to divide up in such a way that, even when starting under full load, there shall not be an arcing voltage between the contacts. Generally speaking, it is correct to divide geometrically throughout.

High Voltage.—One of the objections to strictly geometrical dividing, in the case of high voltages, is seen in the fact that, although the increment is constant for constant torque, the P.D. between contacts is high, and the sparking may be more serious than in the case just considered. It frequently happens in starting motors that irregularities are discovered in the driven machinery just at the moment of starting, and the most natural manipulation by the operator is to move the lever back, contrary to printed instructions supplied with most starters, and rapid deterioration must, of course, result. This can be overcome by limiting the P.D. to a predetermined amount. The author has found that when this figure does not exceed 30 to 35 volts, the amount of sparking, even with currents of 200 to 300 amperes, is so small that very little deterioration of the contacts takes place. Further, the contacts, instead of being widened apart, may be placed as close as $\frac{1}{16}$ inch together, and even when the switch is moved back to re-insert resistance, the arc formed cannot be maintained across the gap. As an actual example of a resistance graded in this manner we may take one for a motor of 10 H.P. at 500 volts, full-load current approximately 17 amperes, armature and series field resistance 1·8 ohms, total resistance approximately 60 ohms, *i.e.*, half full-load current on first step. Maximum increment 20 per cent. of full-load current. Maximum difference of potential between contacts not to exceed 35 volts; 1·8 to 11·4 ohms is divided geometrically on slide rule, using ·8 inch on lower scale (10 inch rule) as factor. At this point the resistance of section 10 is 1·9 ohms, and with the full-load current will absorb 32·5 volts. If the geometrical division is carried further, the P.D. specified will be exceeded, therefore equal sections of 2 ohms are now taken until 29·5 ohms (the resistance at which the full current only can pass) is exceeded. This completes other 10 sections at 31·4 ohms, the last of which (29·4 to 31·4) measures ·28 inches on rule. This, then, is the mechanical value of the new factor with which to divide geometrically up to the total resistance required. The least number of sections is here used for a given current increment and P.D. between contacts, and it will be seen that the resistance is practically divided into three parts (not necessarily equal), the outers divided geometrically, and the centre equally. Under certain conditions it is preferable to use the same gauge for the centre part, and as this ensures uniformity in manufacture a serious practical difficulty is partially removed. On the other hand, when the current taken by the motor is very large in comparison with the volts of supply, the P.D. at the full-current point[1] with the maximum-current increment allowable may be so small that it will be found best to increase the common factor gradually so as to maintain the same momentary rise of

[1] The point in the resistance at which the full-load current only can pass with the armature stationary.

current until a point is reached at which the P.D. will have increased to the maximum permissible, from which point the division is carried on to the total resistance employed, using the new factor as found in a similar manner.

Barrel-Type Controller.—These are regarded by many engineers with much favour, and are preferred in many specifications to those of any other type. The author regards the barrel type of controller as the worst type in use. Owing to the diameter of barrel being usually limited to about 6 inches, the number of steps between off and full speed is usually only six or seven, no matter what size the motor and how high the voltage. This gives rise to arcing, and has led to making these controllers with renewable and removable contacts. The small number of sections will not permit of geometrically dividing, as although the current increment would be equalised, the high volts on the first steps causes serious sparking and burning of contacts. No rule can be given for such onerous conditions, but a compromise can be made by reducing the current increment on the first steps (and consequently the voltage), and increasing both at the armature end. The deterioration of contacts is in this way reduced and equalised to a remarkable extent. Such controllers can only be tested with the motors in the actual machines they are intended to drive, for although it is quite easy to imitate the load in the test-room, it is generally impracticable to imitate the conditions of inertia existing in the driven machine. The current increment shown on the diagram for a series motor is in excess of those observed under any condition with series winding, owing to the fact that an increase of current strengthens the field, lowers the corresponding speed, and consequently the motor gives a higher momentary back E.M.F. than that by which the curve is calculated. In series-parallel controllers the problem of correctly dividing the resistance is made more difficult owing to the fact that certain sections of the resistance must do double duty, acting first in the series arrangement, and, secondly, in the parallel arrangement. It is, of course, necessary to re-insert resistance when changing over from series to parallel, otherwise the effect is practically equivalent to short-circuiting the motor with half the voltage of supply. On the other hand, if too much resistance is re-inserted the motor will actually be reduced in speed, and observation points to the correct amount being more a matter of guess work and experience rather than calculation.

The author offers the following method of solution, taking as an example a motor taking 60 amperes at 250 volts with sufficient resistance to limit the current to 20 amperes on first step. The internal resistance of the motor is 1 ohm in series and ·25 in the parallel arrangement. There are to be three steps of resistance in the series arrangement, the last of which is to be split into two for the parallel arrangement. For the series arrangement the total resistance required is—

$$\frac{250 \text{ volts}}{20 \text{ amperes}} = 12{\cdot}5 \text{ ohms},$$

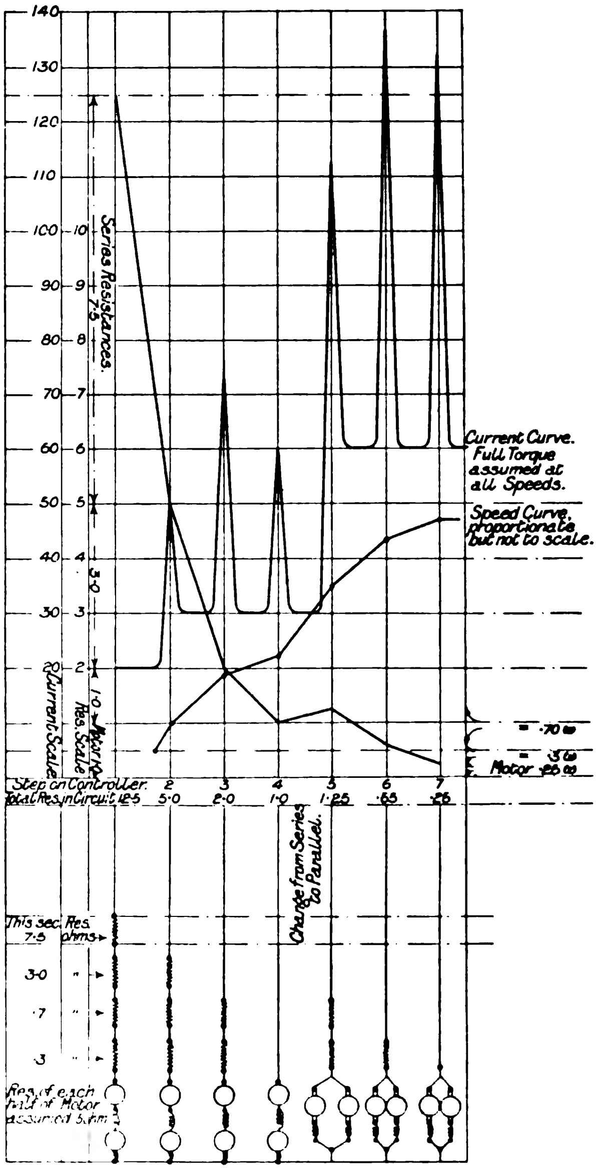
and with 1 ohm as the armature resistance, the values 12·5, 5·37, 2·32

will give a strictly geometrical ratio (to be afterwards modified). The differences between these figures give three sections of resistance of 7·13, 3·05, and 1·32 ohms, of which the last is to be modified and subdivided into two sections for the parallel arrangement. In the latter case the internal resistance of motor is ·25 ohm, and the total resistance forming the other extreme of the geometrical ratio must be such that in changing over from series to parallel with this amount in circuit, there should be no alteration in speed. Owing, however, to the small number of steps provided in the controller it is imperative to accelerate speed in changing over, and it is therefore necessary to add one to the number of sections required in order to discard the "extreme" necessary for the calculation. Thus, the direct E.M.F. necessary to overcome the internal resistance of the motor when running in the series arrangement is 30 amperes $\times$ 1 ohm $=$ 30 volts, and the back E.M.F. is therefore 220. In changing over, the back E.M.F. is instantly halved—*i.e.*, 110 volts—and the amount of resistance to be reinserted without change of speed must be sufficient to absorb 60 amperes with the direct E.M.F. available. This is therefore—

$$\frac{250-110}{60} = 2\cdot 3 \text{ ohms.}$$

Now taking this value as one extreme, the motor resistance as the other, and allowing one extra section for discarding the extreme, we get 2·33, 1·11, ·525, and ·25. Omitting the first value and taking the differences between the remaining three, gives ·585 and ·275 as the values of the two sections of resistance to be employed in the parallel arrangement. The sum, ·86 ohm, is much less than the value 1·32 already determined for the series arrangement, and some compromise is necessary, as these values must be alike. The least alteration should be made to the parallel value, and by making these ·7 and ·3 and the series values 7·5, 3, and 1, a practical subdivision is attained without much interference with the length of the peaks. The characteristic of this controller, which is a standard tramcar type, is fully illustrated in Fig. 3. Any departure from good grading in the resistance results in abnormal current demands an objectionable and violent acceleration, particularly when the car is light. Such controllers are provided with a reversing barrel, thus giving seven speeds in either direction, but the author suggests the necessity of a new type giving, say, twelve forward speeds and only two backward ones, as a means of reducing the current demands to something nearer to the normal rating of the motor. The forward contacts at one end of the car would, of course, be cross connected to the backward ones at the other end of car.

Mechanically-Operated Switches.—Before leaving the subject of metallic resistances, it is necessary to point out a particular modification demanded in starters in which the resistance is automatically cut out by the driven machine while accelerating up to full speed. The various sections of the resistance are cut out at intervals which are inversely proportional to the "instantaneous speed" of the driven machine; and even when the resistance sections form a geometrical



140
130
120
110
100 10
90 9
80 8
70 7
60 6
50 5
40 4
30 3
20 2
Series Resistances. 7·5
3·0
1·0
Current Scale.
Res. Scale
Motor
Current Curve. Full Torque assumed at all Speeds.
Speed Curve, proportionate but not to scale.
= ·70 ω
= ·36 ω
Motor ·26 ω
Step on Controller. 2 3 4 5 6 7
Total Res. in Circuit 12·5 5·0 2·0 1·0 1·25 ·65 ·26
Change from Series to Parallel.
This sec. Res. 7·5 ohms
3·0
·7
·3
Res. of each half of Motor assumed ·5 ohm

FIG. 3.

ratio, it may happen that insufficient time is allowed between the final steps for the current to become steady before the next section is cut out, and, in consequence, the peaks in the current curve are superimposed, with the result that the final increment is much greater than the initial increment. Where the number of sections is small the minimum increment with a geometrical ratio is necessarily large, and the final superimposed peaks may be large enough to cause serious sparking at the motor, if not also at the switch. This can be compromised by using a diminishing factor from the starting to the armature end, and the superimposed reduced increments at the armature end will tend towards a uniform current increase throughout. A serious objection to this type of switch is that it is necessary to pass at least the full current on the first step in order that the driven machine (say, a hoist) may deal with the maximum load, otherwise the machine will not start and resistance cannot be cut out.

Liquid Resistances.—The author now desires to apply the foregoing considerations to liquid resistances. There is no doubt that this type offers the best solution of all difficulties, and when carefully designed affords the most perfect method of control, particularly with reversing motors. Most liquid resistances, however, have at least one or two defects—*i.e.* (1) The current cannot be sufficiently reduced when the dipping-plate is just entering the liquid; and (2) the resistance cannot be sufficiently reduced with the plate all in before short-circuiting the starter, and the consequent rush of current seriously damages the switch parts and abnormally stresses motor and machine. Either of these defects may be remedied at the expense of the other by varying the density of the solution employed. A fallacious method of remedying both defects is by making a small projection on the dipping-plate touch a similar projection inside the pot, the actual surface in contact being frequently less than a square inch. The intention is, of course, to reduce the resistance gradually down to zero. Owing, however, to the great divergencies in the conductivities of the metal pot and the solution employed this object is not attained, and when the gap is open only a very short length a large amount of energy becomes concentrated in a very small space, and arcing and violent ebullition results. A better method of overcoming both defects consists of enamelling the pot half-way down on the inside, and arranging the dipping-plate to pass between two other plates cast into the pot. The enamel compels the current to pass through a greater length of solution at starting, and gives much better control. The second defect is overcome by the plate arrangement, in which it will be seen that the dipping-plate passes close between two others so as to reduce the resistance to a minimum by presenting large surface areas to each other. The fixed plates are provided with suitable apertures to permit free circulation of the solution. Several starters on this principle have been in use on large motors for some years, and give no trouble whatever, even on 500 volts.

Regulating Resistances.—Before leaving the subject of starting resistances a few observations on resistances for regulating purposes only will be opportune. In many motor equipments the starting and

regulating switches are two entirely distinct pieces of apparatus, although constructed on similar lines with similar materials, the only difference being that the starting resistance is graded more or less correctly, while the regulating resistance is divided into equal sections of resistance, and is one gauge of material throughout. Such an arrangement gives satisfactory speed variations, and is generally preferred, although an independent regulating resistance is not without disadvantages, the most serious being that if the switch is moved while the motor is running under load, all the violent current demands previously shown are introduced. For this reason the author strongly condemns the separate regulating switch, and maintains that these should be combined with the starter, the gauge of the materials being sufficient for continuous running.

Suggested Rule for Starters.—As has already been pointed out, considerable divergence exists in the specifications of consulting engineers and supply companies as to what is required in a starter, and the following suggested rule may prove a base for a more uniform statement : thus, "Current on first step not to exceed 10 amperes, or half full-load current, whichever is least, but for motors taking more than 50 amperes, 20 per cent. of full-load current. The momentary increase of current in cutting out any section of resistance not to exceed 10 amperes, or 25 per cent. full-load current, whichever is least, but for motors taking more than 50 amperes, increment may be 20 per cent. of full-load current." In the interests of the purchaser the following addition may be inserted : "The E.M.F. across any section of the resistance shall be limited to an amount which shall not cause injurious sparking or rapid deterioration of the contacts."

Conclusion.—There are many other details of starters which would be benefited by an open discussion, such as "motor field connections and buffer resistances," "dissipation *versus* absorption of heat in and about the resistance material," "means for using the whole of the material in the final sections and so diminishing the bulk," "quality and capacity of the various materials employed," etc. ; but the author hopes that his arguments for better grading alone may bring about a spirited discussion, and draw more serious attention to what is now a mere secondary detail of transmission work.

Mr. Dobbie

Mr. R. S. DOBBIE : In speaking of the starting of motors by very small increment, I believe some supply companies only allow current to go up by 5- or 10-ampere steps, and with this I am quite at variance. Just imagine, in an elevator or other device that had to be put in motion and stopped frequently, the motor being operated by 5- or 10-ampere steps when the maximum current to start movement would require to be 70 or 80 amperes ; as, for instance, the controllers which are used in the Sprague lift on the Central London Railway. There are only three or four points which the operator in the elevator can manipulate. Imagine what time it would take if 5-ampere increments only were allowed, with presumably a pause at each. In many cases motors will be found to start better by the sudden application of a large current, say that of full load, so that the slack of belts and gear

enable a certain inertia to be obtained. A case in point is one of a motor requiring usually 70 amperes to run. On Monday morning, when the machinery is stiff from oil not being in the many bearings, this motor takes 250 amperes or more to start, and it would be a great waste of time to go over a very large number of steps in order to effect a start when three or four would easily do it. Again a large number of steps may be provided, but it would be impossible (without some complicated devices) to sweep over a large number of them quickly and have practically the same effect as a single step as far as the tendency to lower E.M.F. on the circuit is concerned. It would be interesting to know if the supply companies referred to have any time limit on each step in the use of the starting switch. Mr. Dobbie.

The way in which the author treated the starters made of metallic resistances was masterly, and I am sorry he has not dealt more fully with liquid switches, although I must say the one he has showed us is certainly most ingenious and valuable. One defect has always troubled me with liquid switches; they are never made big enough for the work they are intended, or rather supposed, to do. I remember an instance of a liquid double-pole switch for 300 amperes, I used it as a single-pole switch, with all the tanks in parallel for 200 amperes, and yet it was not sufficient.

Mr. C. TURNBULL: One speaker remarked that it was absurd limiting motors to 10 ampere steps, as some motors would not start with less than 70 amperes. But station engineers would not care to have Central London Railway elevators run from their lighting mains. Where the demand for power is great, it is better to have separate mains for power. When the power-load goes off, say after 5 o'clock, the power mains may be interconnected through switch pillars in the town with the lighting mains. Mr. Turnbull.

Mr. H. H. BIGLAND: I am sorry we have not heard any remarks on the starting resistances, of which there are one or two forms in graphite or some carbonised material. Mr. Marquand has worked in that direction and has met with an amount of success, though perhaps more particularly with arc-lamp resistances; and I think Mr. Ferranti has also had something to do with resistances of the kind. Mr. Bigland.

Mr. GEO. RALPH: Mr. Gott states that "*series* motors up to 2 H.P. can be safely started without resistance in circuit, but only the *very smallest* sizes of *shunt-wound* motors." He does not state what size, but I imagine he places the limit at about ¼ H.P. It is quite common practice in workshops to start shunt-wound motors up to 1½ H.P. on 110-volt circuits with a simple switch, no resistance whatever being put in circuit, and the motors are none the worse. Of course the conditions in a works supplying its own electrical energy are different to those taking current from a public company's or corporation's mains, and it is possible that the suppliers might object. Mr. Ralph.

Another method of starting larger motors in a simple manner may be of interest, though perhaps not bearing directly on the subject of the paper. In the case of some overhead travelling cranes—single-motor type—there was a single step of resistance in circuit when at rest. This resistance was so proportioned that when current was

Mr. Ralph. switched on to the armature and *shunt-wound* field, not more than the full-load current could pass. This resistance was short-circuited automatically by the motor field-magnets. When the field-magnets attained their full strength they attracted an iron armature against the pull of a spring, and in moving this armature short-circuited the resistance. The time interval of the field attaining full strength was about 7 or 10 seconds in the case of a 10 H.P. bi-polar shunt-wound motor, and this time was sufficient for the motor armature to accelerate to its full speed, when started up *light*, or as nearly light as the conditions of the belts or gearing permitted. There was no heavy rush of current or sparking when the resistance was short-circuited.

Mr. Clatworthy. Mr. W. A. CLATWORTHY: I would like to suggest that, where slow motion starters are specified, the time which it would take from the closing of the circuit to the last contact of the starter should also be specified. One can easily see that if a motor is driving an inert load and the starter goes on too quickly a very large current will flow, and I consider that if the 5- or 10-ampere rule be insisted upon it is equally important that a certain period of time should be stated in which the resistance is to be cut out. Some information with regard to the character and design of resistances, both in regard to mechanical strength and to the best form of construction which will ensure them being impervious to moisture, would have been appreciated. I think these are just as important points in a resistance as correct subdivision.

In reference to Mr. Gott's remarks on that subject, there are certain places where I have found it of great importance that the regulating switches and resistances should be quite distinct from the starters, for example, small printing machines, etc., where the regulating switches are fitted with special locks which can be only opened by a key in the foreman's keeping. The foreman then sets the speed of the machines to suit the work, and the operator can only start or stop the machine and run at the fixed speed as set.

Mr. Snell. Mr. J. F. C. SNELL (*Chairman*): In my own experience wire resistances are preferable to liquid resistances, taken all round, and for these I much prefer galvanised iron wire to alloys.

We must congratulate Mr. Gott on the elaborate way he has analysed this question. It is only by analysing these details we make progress, and I am sure you will accord Mr. Gott a very hearty vote of thanks.

Mr. Gott. Mr. A. E. GOTT: In reply to Mr. Dobbie, I venture to state that his view of starting motors with only three or four steps of resistance is the opposite extreme to those of the station engineers, and I do not agree with the practice of switching on large currents *suddenly*. I maintain that no motor should have more than half its full-load current switched on at the first step of the starting-switch, as, being suddenly applied, is equivalent to a live load and the mechanical stresses are therefore equivalent to the full normal load. By limiting the initial current and raising the current gradually to the amount necessary for the motor to start, violent stresses are avoided, and it is not good engineering to permit abnormal stresses when they can be so easily avoided.

Regarding liquid resistances, I have not dealt with this type any further than refers to the grading of the resistance down to zero. Mr. Gott.

Mr. Turnbull refers to the use of separate motor mains, and many of you are probably aware that in some towns, Liverpool for instance, separate power mains exist, supplying motors of large power. The variable load causes a fluctuation of quite 10 per cent., to which the supply authorities make no objection.

In reply to Mr. Bigland, I have not seen many graphite switches and have only carefully examined one specimen, in which the total resistance was excessive for the motor for which it was designed and passed not more than one-tenth of the full-load current on the first step. The sections were graded, but insufficiently, and the last section only permitted little more than the full-load current to pass with a *stationary* armature. It could only be considered a bad switch.

Mr. Ralph states that it is common practice to start shunt-motors of 1 H.P. without a resistance. It of course depends entirely on the nature of the load and the amount of inertia in the machinery driven. In some cases it would be preferable to dispense with the resistance. Mr. Ralph mentions a point in which I think he is wrong. He instances the use of a single section of resistance, passing the full-load current only, with which it would be impossible for the motor to accelerate up to its full speed. [Mr. RALPH: The motor is running light.] If running light it would accelerate up to practically full speed, the difference being due to volts lost in the resistance with the "no load" current. My argument, however, deals with motors under full load, and particularly with machinery of great inertia.

I appreciate Mr. Clatworthy's remarks on the mechanical design of starters, but this is outside the argument of the paper and deserves separate treatment.

Mr. Snell's preference for galvanised iron wire in resistances requires qualification. The various resistance materials in use can be grouped under three or four heads, each suitable for particular combinations of current and resistance. For large current galvanised wire is certainly preferable, but for currents of say 10 amperes and moderate resistance, one of the german-silver compounds, such as "Eureka," may be found more suitable; while for currents of one or two amperes and extremely high resistance there are other materials designed to obviate the use of extremely fine wires by possessing a much higher specific resistance.

In conclusion I thank you for your appreciation of my paper, and must also express my obligation to Messrs. Holmes for necessary data on which to base the arguments.

NEWCASTLE LOCAL SECTION.

ON THE EQUIPMENT OF A MODERN TELEPHONE EXCHANGE.

By F. A. S. WORMULL, Associate.

(Abstract of a Paper read at Meeting of Section, February 17th, 1902.)

After describing the well-known "Series system," the author proceeded to deal with the relay calling and clearing, and the common battery system.

With the *relay* calling and clearing system, the lines, after passing through the test-room, are brought to the jacks in the exchange in a manner similar to that described in the *series* system, the only difference being that the two inner contacts of the home section jack are joined together and connected to a 250-ohm relay to battery and earth. A test circuit described is also somewhat different, the line being engaged by means of an extra spring and contact provided on the jack instead of by the body of the plug and the third conductor of the cord. I might mention that the system of engaging the line is not an essential part of the relay calling system. I have elected to describe this method as an alternative to the method given on the series system. You will notice that on the insertion of the plug the line springs are lifted from the inner contacts, thus cutting off the relay and battery, and the test spring is also lifted from contact with the test ring, and pushed outwards, and forced in contact with a stud, connected to which is an earth battery. The test springs of each jack of the same number in the exchange being joined together, and in their normal position in contact with the test rings, the current of the earth battery will be on the test ring of each jack in the exchange, corresponding with the number of the engaged line, except the test ring of the jack into which the plug is inserted. The armature of the 250-ohm calling relay is connected to one side of the battery, and a contact to which the calling lamp is brought is provided in such a position that on the relay being energised the armature will close the circuit through the calling lamp, and for each operator's position a second relay of very low resistance—about two ohms—is provided, connected in the return wire common to the bank of calling lamps forming that position. The armature of this relay is connected to the positive side of the battery, and the contact joined to the pilot lamp and supervisory lamp on chief operator's table in series; this relay, being in series with all the line relays for the operator's position, will respond simultaneously with any one of them. From the supervisory lamp the circuit is carried through the night-bell switch to the negative pole of the battery; or if the night-bell switch is to the night position, through another two-ohm relay, the contact on the night-bell relay being through bell to battery. The night-bell relay

is, as its name denotes, for the purpose of giving an audible signal, in addition to the visual signal, after the busy hours of the day.

The operator's connecting-cord circuit is shown in detail on Fig. 1. The two tips and two bodies of the plugs are joined together, and connections are taken through the listening key, through the ringing key, and differentially-wound secondary of the induction coil to the receiver, the centre point of which is to earth, through a 2,000-ohm simple resistance ; the object of this resistance being to reduce the amount of current passing through the receiver, and consequently the click, which might otherwise be detrimental to the operator's hearing. It will be noticed from the diagrams that the operator's receiver in this, as in the series system, is in the middle of the secondary of the induction coil. With the listening key in the through position the instrument is cut out, and the line is bridged by a differentially-wound retardation coil, the centre point of which is connected to a 250-ohm relay, thence to the negative pole of the earthed battery. The armature of the clearing relay is also connected to the same pole, and the relay contact to the clearing lamp and earthed side of the battery. The microphone circuit is also interesting, for, as it works off the common battery of 24 volts, it requires to be specially dealt with to protect the microphone from the excessive current, and for this purpose a 160-ohm retardation coil is placed in circuit shunted by a condenser of two microfarads capacity.

The subscribers' instruments, although not properly within the scope of this paper, require a little description, for, in addition to the magneto ringer necessary in the series system, a special calling-key relay has to be provided (this relay is shown on Fig. 2). One end of the relay coil is connected to the subscriber's line wire, and the other end to the frame of the relay ; a special stud with

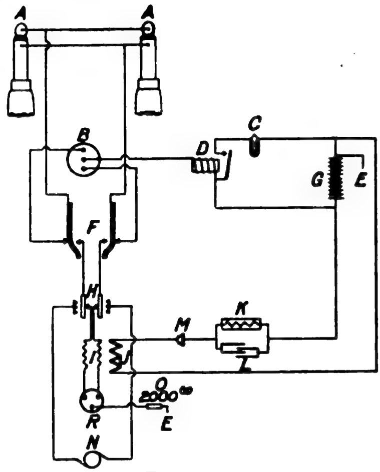


FIGURE 1.

A A are connecting plugs bridged by a differentially-wound retardation coil B, the centre point of which is connected to the clearing relay D ; and in its local circuit the clearing lamp C is included.

G is the central source of energy common to the whole Exchange.

F is the listening key. H is the ringing key.

I and J are the secondary and primary of the operator's induction coil respectively.

M is the microphone.

K is a retardation coil in the microphone circuit, shunted by condenser L.

R is the operator's differentially-wound receiver, connected to the two inner ends of the differentially-wound secondary of the induction coil, the centre point of the receiver being to earth, through a 2,000-ohm resistance coil.

N is the generator for supplying the calling-current.

adjustable contact is connected to earth, and so placed that on the armature being depressed by means of the call button, the subscriber's line is earthed through the coil of the relay.

The operation of the system is as follows: A subscriber desiring to initiate a call, presses the call button, thus earthing his line as previously described. This draws a current from the central battery, through his line relay, over both lines, through the call-key relay. Both relays being thus energised, the calling relay is held down, the line signal relay being also in operation, causes the lamp in the exchange to light, signifying that the subscriber requires attention, the lamp remaining alight until the current is removed by the insertion of the operator's plug. The cutting off of the current at the exchange releases the armature of the line signal relay, and extinguishes the lamp. It also

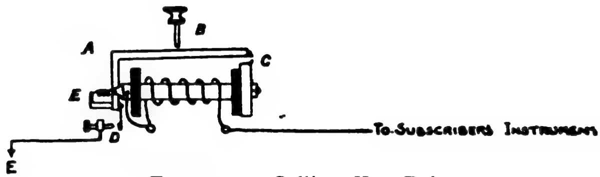


FIGURE 2.—Calling Key Relay.

A is a movable armature controlled by call button B, and controlling a movable contact D for earthing a subscriber's line.

C is a pole extension piece for retaining the armature A when the relay is energised.

E is a spiral spring for bringing the armature back to zero, when the current is removed from line.

allows the calling-key relay to return to its normal position, thus signifying to the caller that the operator is on the line. After the number has been taken and the connection made, the listening key is put up, and the clearing relay is then in circuit. On completion of the conversation either subscriber can give the clearing signal by pressing his calling key, which earths the line and draws current from the central battery through the clearing relay, through the differentially-wound retardation coil to lines, and calling-key relay to earth, thus bringing both the clearing relay and calling-key relay into operation, lights the clearing lamp at the exchange. This remains alight until the operator pulls down her key, cutting off the central battery, extinguishing the lamp, and causing the button of the subscriber's calling key to return to normal, thus giving him a visual indication that his line has been cleared. With this system it is possible for any two subscribers to convert their exchange line into a private line—that is to say, after obtaining communication with the desired number, they can ring one another by means of their magneto-generators without actuating the clearing lamp at the exchange, but either of them can obtain the attention of the exchange by pressing their call button.

The number of movements necessary on the part of the operator to effect connection by this system is four—viz.: (1) insert plug and answer; (2) insert corresponding plug in number wanted; (3) press button to ring subscriber; (4) put up listening key; and for a dis-

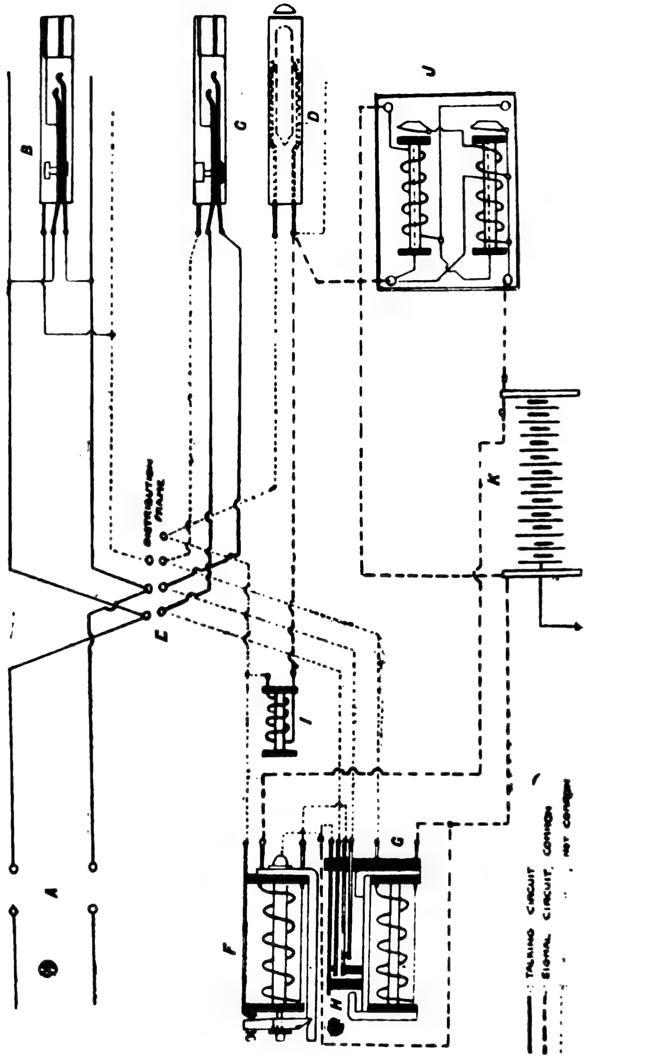


FIGURE 3.—Showing the Connections of the Line on the Central-battery System, the Speaking-circuit being distinguished from the Signalling-circuits by Continuous Lines.

A is the test-board.
E are tabs on the distributing frame.
B is one of the jacks on the multiple of the switchboard.
C is the home-section jack.
D is the line signalling lamp corresponding to the home-section jack C.
F is the line-signal relay. G is the cut-off relay.
H are the cut-off springs controlling the circuit through F.
I is the resistance-coil shunting the signal lamp.
J is the night-bell relay, which also controls pilot lamp. This is common to the whole of one operator's position.
K is the battery common to the whole of the Exchange.

connection, two: (1) pull down listening key, thus putting out the lamp; (2) pull out cords. The current necessary for working this system is obtained from an 11-cell accumulator, charged by preference by a motor-generator working off the town mains. It is necessary, of course, to duplicate both the battery and the motor-generators, so as to avoid the possibility of a failure of current due to breakdown of the generators or accident to the batteries.

The third system is what is generally known as the Western Electric common battery relay switchboard, in which system the current both for signalling and for speaking is supplied from the central source of energy, thus removing from the distant station one of the most fruitful sources of trouble—viz., the battery for working the transmitter. The lines, after passing through the test-room, are brought to a distribution frame. This consists of a series of double tabs, arranged in groups of three in blocks of 60 on the one side and in groups of four double tabs in blocks of 80 on the other. These blocks are supported on an iron frame, one side in horizontal rows and the others vertically. The two sets of tables are held about 3ft. 6in. apart, and insulated rings are provided midway between them. The lines from the test jacks are brought to the horizontal side of the frame, and cables from the multiple of the switchboard are brought to the same set of tabs and soldered to one side, the cable from the switchboard containing 63 wires laid up in threes, the odd wire being that in connection with the test circuit. From the four-way double tabs on the vertical side cables are led to the home section jacks and calling lamps, and also to the relays controlling same, four wires for each subscriber's circuit being taken to the switchboard—viz., two to the line springs of the home section jack, one to the test circuit, and a fourth to the calling lamp. Four wires are also carried to the relay frame, two from the line tabs to the cut-out springs of the cut-off relay, one from the test tab to the winding of the cut-off relay, and the fourth to the calling-lamp contact on the line relay. It will thus be seen that the lines on the horizontal side of the distribution frame are arranged in numerical order, or similar to that of the multiple of the switchboard, and on the vertical side in order of the home section jacks and calling lamps. The object of this distribution frame is to enable the work of each operator's position to be equalised by distributing the very busy subscribers equally between the operators' positions. This is done without disturbing the numerical arrangement of the subscribers over the multiple. The fact of the subscribers not being in numerical order on their calling lamps is not important, as the calling lamp of each subscriber is placed adjacent to his home section jack, and all connections with the numbers wanted are made on the multiple.

The second use of the frame is to provide a convenient point at which the wires between the home section lamps and the relays and the lines from the testboard and the multiple can be joined. The distribution of the lines over the operators' positions is made by three-conductor cable, each wire being separately insulated, and the whole covered with an asbestos braiding. The three wires are coloured

green, pink, and purple respectively, the green and pink being soldered to the line tabs, and the purple to the test tabs on the horizontal side of the frame. They are then passed through the insulating rings corresponding with the operator's position on which the subscriber's calling lamp is situated, and soldered on to the first three tabs, which are connected to the two lines and test of the home section jack. The relays are fixed on an iron frame in the same room, and arranged in bays and in rows of 10, the line and cut-off relays being

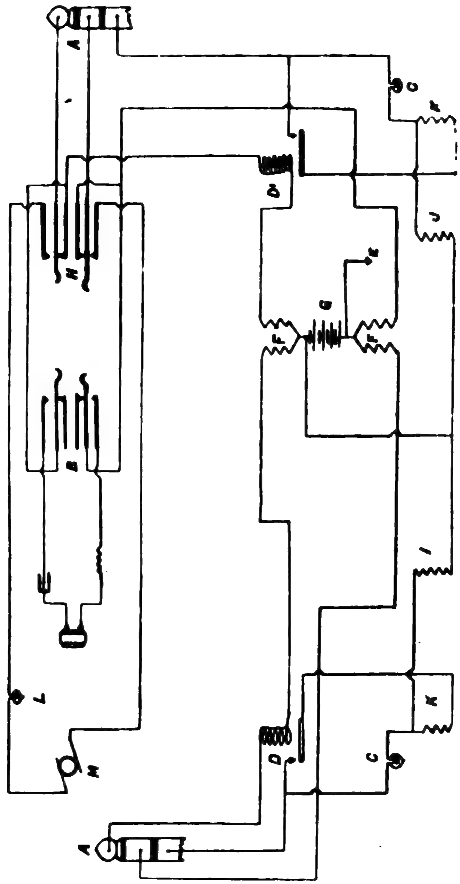


FIGURE 4.—Connecting-cord Circuit with Common Battery System.

A A are connecting plugs.
C are the supervisory lamps controlled by the supervisory relays D and D'.
B is the listening key. H is the ringing key.
I and J are 83-ohm coils. K K are 40-ohm coils.
F and F are two halves of repeater coils. G is the battery common to the Exchange.
M is the calling generator. L is the resistance lamp in the generator circuit.

fitted on the same base plates. These are arranged in the same order as the vertical tabs on the distribution frame—viz., in the order of the home section jacks on the operators' positions. I have a sample of the line and cut-off relays here, but perhaps they deserve a short description.

The line relay consists of a single coil wound to a resistance of 83 ohms, and in front of the free end of which is a disc armature, turned to a knife-edge, and balanced in a slot in a piece of iron, which forms an extension to the pole of the relay nearest the base plate, the disc being controlled by a regulating screw through the centre. In the front of the relay a contact point is provided, to which the calling lamp is connected, and in such a position that when the armature is attracted a circuit is formed through the disc armature and the contact point referred to.

The cut-off relay is slightly more complicated. It consists of an electromagnet wound to a resistance of 37 ohms. The pole-piece of the free end of the magnet is extended, and bent at right angles, so as to be parallel with the core, and overlapping the outside of the bobbin. A flat armature is supported on a pole-piece fixed to the base-plate end of the magnet. Parallel with the armature, four spring contacts are fixed normally in contact in pairs. The outer springs are controlled by insulated studs on the armature, so that when the relay is energised, the two pairs of springs are lifted apart and the line signal circuit broken.

The repeater coil, which is placed between the battery and the connecting cords of the operator's set, consists of four coils of equal resistance (37 ohms) wound in pairs round an iron core, the two coils to the positive side of the battery to which the tips of the cords are connected being wound on the right-hand side of the core, and the two negative coils, or those connected to the rings, on the left. The two wires of each pair, being wound on together, are equal in the number of turns, and also equidistant from the core. The object of this repeater is to divide the cord circuit into two parts for signalling purpose, without interfering with the efficiency of the speaking circuit. The 63-wire cable from the horizontal side of the distribution frame is carried through multiple of the switchboard, first to the jacks on the junction section, then on to the subscriber's sections, in a manner similar to that described in the series system. The jacks, however, in this system differ from those previously described, the lines being carried through the board in parallel, so that the insertion of a plug in the first jack of the multiple will not disconnect the remainder of the board. The advantage claimed for the parallel jacks over the series jacks is that the number of loose contacts in the circuit is reduced. The test circuit in this pattern jack, as in the former, is completely insulated from the line springs, and extended so as to pass through the winding of the cut-off relay. The home section jacks and lamps are arranged in groups of 100, each group forming an operator's position, and immediately in front of which the operator's connecting cords and supervisory lamps are placed. The operator's set and connecting-cord circuits are very much more complicated in this system than in either

of those previously described. Three-point plugs are used in conjunction with three-conductor cords, a combined ringing and speaking key, special repeating coil and relays for controlling the clearing lamps.

The connecting-cord circuit is as follows: From the tip of the answering plug connection is taken through the coil of the relay controlling the supervisory or clearing lamp of the answering plug, through one-half of the repeater coil to the relay controlling the clearing lamp of the calling plug, thence through listening key to tip of calling plug, from the ring of the answering plug through the other half of the repeating coil, through listening key back to ring of calling plug, from the body of the answering plug through the answering plug clearing lamp, to an 83-ohm simple resistance coil, thence to negative side of battery; from the body of the calling plug, through the calling plug clearing lamp, through 83-ohm coil to battery. There is an alternative path for the current from the battery to body of plugs through a 40-ohm simple resistance, this path being controlled by the armature of the supervisory relays.

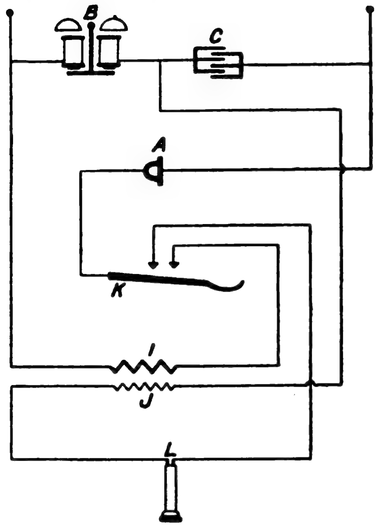


FIGURE 5.—Connections of Subscribers on Central Battery Instruments.

A is the microphone.

B is the high-resistance magneto-bell bridged across two lines through condenser C.

K is the switch-hook, which automatically closes the primary and secondary circuits on the removal of the receiver.

I and J are the primary and secondary of the induction coils to L the receiver.

In order that the calling circuit may be followed, a short description of the subscribers' instruments must be given. These consist of a specially-wound induction coil, having a ratio of 1 to 2, transmitter, receiver, switch-hook, magneto-bell, and a two-microfarad condenser, joined up as shown on Fig. 5. It will be seen that when the receiver is on the hook the circuit is open as far as continuous currents are concerned, but a circuit is available for alternating currents through the condenser and magneto-bell. When the receiver is off the hook, the two lines are short-circuited through the 15-ohm primary and transmitter.

A subscriber's calling circuit is as follows: From the "A" line through cut-off springs on the cut-off relay, to winding of signal relay, to negative side of battery. From the "B" wire to cut-off springs on cut-out relay to positive side of the battery. A subscriber removing his telephone from the hook closes the circuit through the low resistance of

his primary, thus energising the signal relay, which closes the local circuit in which his signal lamp is connected, indicating to the operator that he requires attention. On the operator inserting the answering plug the cut-off relay is energised by the current from the body of her plug, passing through ring of calling jack, through the winding of cut-off relay, to positive side of battery. The lifting of the armature of the cut-off relay forces the cut-off springs apart, thus breaking the circuit between the subscriber's line and calling relay and extinguishing the signal lamp. The number wanted being ascertained the operator takes the corresponding calling plug, and taps on to the ring of the jack of the number asked for, and if her receiver remains silent inserts the plug. The current on the body of the calling plug causes the supervisory lamp to light, which remains alight until the wanted subscriber removes his telephone from the hook. The supervisory lamp of the calling plug is extinguished when the supervisory relay becomes energised by the current drawn from the battery through the ring of the plug, through the primary of the subscriber's instrument, back to the tip of the plug and battery. This shunts the current from the supervisory lamp through the alternative path before mentioned; or, in other words, the insertion of the answering plug cuts the line relay out of circuit, and inserts the supervisory relay for the reception of any subsequent signal from the calling subscriber. The insertion of the calling plug cuts the circuit of the line relay of the wanted subscriber, thus preventing a call being given on the home section lamp, when he removes the receiver from the hook to reply to the call. The supervisory lamp of the cord circuit now becomes his means of signalling with the exchange. On a connection being completed, and both supervisory lamps extinguished, the operator knows that the two subscribers are in communication: the hanging up of either of the subscribers' receivers will cause the lamps to light, and when both lamps are alight the operator knows that the conversation is completed, and proceeds to withdraw both plugs without challenging the line, which restores the line calling relays to their normal position.

The number of movements to effect a connection in this system is four—viz: (1) insert plug and answer; (2) insert corresponding plug in number wanted; (3) ring subscriber wanted; (4) replace listening key; and for a disconnection, two: (1) pull out plugs; (2) pull over listening key.

The current for working this system, although normally taken from a set of 11-cell accumulators, is actually, during the busy hours of the day, taken direct from a specially-wound dynamo, with the acumulators bridged across the discharge mains, the unutilised current from the dynamo being absorbed by the cells. The dynamo is a six-pole shunt-wound machine, driven at 1,000 revolutions per minute, capable of giving a current of 200 amperes at 30 volts, and is coupled direct to a 12-H.P. four-pole shunt-wound motor, running off the town mains.

Mr. Snell. Mr. J. F. C. SNELL (*Chairman*): I am sure you will all join in a hearty vote of thanks to Mr. Wormull for his excellent paper, the first of its kind read before this Section.

Mr. ALEXANDER MOIR: Mr. Wormull has stated that telephony was progressive, and I think he has proved that, whatever else may be said about the National Telephone Company, those who are responsible for the direction of its engineering policy have not fallen asleep. For example, six years ago a paper on telephone exchanges was read before the Institution by Mr. Sinclair, Engineer-in-Chief to the Company; he then found it necessary, in making reference to the arrangements within the exchanges, to mention frequently single-wire telephone circuits. Mr. Wormull has not done so, and we may therefore assume that this rather imperfect system has passed out of existence. Again, the most up-to-date system in 1896 was that first mentioned in Mr. Wormull's paper to-night: so that the newest in 1896 has become the oldest in 1902. Mr. Moir

Mr. Wormull laid down the conditions which should regulate the designing of a telephone exchange, and we find no fault with these. Where complication is necessary it is better to have it at the exchange, under the eyes of skilled people, than at the renter's office. He was, however, careful not to express preference for any of the three systems he described, and in this he was prudent, for in telephony, as well as in other things, it is well to be fully on with the new love, to get to know as much as you can about her, before you say goodbye to the old.

There is no doubt that the common battery system which Mr. Wormull described last, has gained a considerable foothold in this country. The Post Office have decided to adopt it in London, and it is being introduced in several of the Company's exchanges, but whether it will supersede all other systems remains to be seen. If they have to do so, the National Telephone Company will say goodbye to the magneto ringer with much regret. I am in sympathy with the automatic calling system, which has been used by the Post Office for, I may say, a generation, but I have always thought that the magneto ringer was an instrument which peculiarly appealed to the, shall I say, "evil" temper of the telephone user. With the automatic call system, should a few seconds elapse before the exchange answers, it is trying to the patience of a subscriber, the reason being that the whole of his energy is focussed in straining to hear the operator's voice; seconds seem as minutes. But give him something to play with, a handle to turn, and he will remain happy for quite a long time. I should like to have heard a few words in connection with extension circuits connected to the common battery system, but probably this hardly comes within the scope of the paper. At some future time some of our members may take this and other accessory subjects up, such for example as the party line circuit and junction line equipments.

Mr. C. TURNBULL: Some years ago I invented an electric bell which I submitted to the Telephone Company, who approved of it. I was pleased to find to-night that it was Mr. Wormull who had reported well on it. Unfortunately I found it impossible to get English manufacturers to take any interest in a bell that was different from what they were accustomed to, although I understand that the Americans are going in for it. It appears to me that to deal with intricate work, such as Mr. Wormull deals with, a style of education will Mr. Turnbull.

Mr. Turnbull. be needed quite different from the mediæval training now given to schoolboys, and the sooner it comes the better.

Mr. Gott. Mr. A. E. GOTT: I gained some knowledge of exchanges, as then constructed, in the early 80's, and I am much impressed with the marvellous development which has been made during the last few years. It may be of interest to describe the arrangements in use at the time referred to. The exchange as then constructed was very simple indeed. The line wires, after passing through the test board and lightning arresters, were led to a switchboard consisting of very ordinary drop, indicators, and thence through suitable contact springs to earth. The operation of answering a call consisted of inserting a plug, with flexible cord attached to operator's circuit, into a receptacle below the indicator thereby disconnecting the earth and placing the operator in communication with the subscriber. Having ascertained the required number, the operator's plug was withdrawn and a flexible cord, with a plug at each end, was used to connect the two subscribers. These plugs were differently constructed in such a manner that one subscriber's indicator, was left in circuit for the purpose of calling off by the ringing current when conversations were completed. Such a system was limited to two or three hundred subscribers, and the connecting cords caused great confusion. The most serious objection was in the cords, which frequently developed complete breaks between the plugs, with the result that both subscribers were shut off from each other and the exchange, and generally remained so until one or both made a personal call on the manager.

Mr. Snell. Mr. J. F. C. SNELL (Chairman): I should like to congratulate Mr. Wormull upon the very evident care which has been taken with this paper and the amount of detail he has put before us. I should like also to say that the Sunderland exchange, which I had the pleasure of going over some little time ago with Mr. Wormull, is really a model of neatness, and far from station engineers having a contempt for men who go in for telephony, it seems to me they have much to learn from them. Many of our engineers in high positions now have been telephone engineers, and certainly telephony appears to be a good "stepping stone to higher things." The Sunderland board was changed over from the old system in two hours, the number of connections being 1,160. Another thing which struck me very much was the absolute quietness. One could hear a pin drop in this particular room. I left feeling a very much greater admiration for telephone work and telephone people generally.

Mr. Heaviside. Mr. A. W. HEAVISIDE: I stand as one who has had experience of both electric light and power switchboards and telephone switchboards, and I can warn all those who have never touched telephony never to do so unless they are prepared for a considerable mental effort. It requires ability of the highest order to manage a large number of circuits of varying use and of varying length, so that every contingency is automatically provided for, including the stupidity of the public and the operator. No game of chess, however complicated, can give any idea of what it is to design a telephone equipment whose antennæ shall be both near- and far-reaching, sometimes merely circulating to a sub-

Mr Heaviside.

scriber's office in the next street and sometimes to one in a foreign land. There is in chess no time when you move one pawn that it does not affect the ultimate result. Similarly in telephony any variation, however innocent it may appear at first sight, may make or mar the whole design—only those who have been through the mill know what it is, and as for putting telephony upon a lower level than electric lighting, I venture to say that the highest form of all electrical knowledge has been found in connection with telephony. It is the most refined application of electricity known.

Mr. Wormull.

Mr. F. A. S. WORMULL (in reply): Mr. Moir has referred to a paper read by Mr. Sinclair about six years ago, where he dealt partly with single-wire systems. Even at that date there were very few towns working on this system, and these have since been metallic-circuited, the reason for the metallic circuits not being then introduced were political, and for these the telephone engineer was not responsible. The self-restored indicator system, in view of the second and third systems I have described, is decidedly out of date, and I do not know of any exchange in the country into which it is being introduced, although some of the older exchanges fitted with these indicators may be extended on the same principle. On the series system I was in hopes that we should have had some considerable discussion, as considerable divergence of opinion exists amongst telephone engineers as to their respective merits, and numerous experts affirm that with the series system, owing to the number of movable contacts in circuit, the liability to faults is increased; and this was so in the older pattern of spring jack, where brass contacts of large superficial area were included in the circuit, but with the newer patterns of series jacks, where you have platinum points making contact with platinum studs, this trouble is almost entirely absent. I have had a series of tests taken on a switchboard where sixteen jacks are in a series, with about 160 yards of switchboard cable, and the resistance of the circuits did not vary more than 1 ohm. With the series jacks it is possible to simplify the apparatus by dispensing with the cut-off relays and their attendant complications; you are also enabled to localise faults through the multiple much more readily; you also prevent the possibility of a triple connection. With the parallel jacks the risk of faulty contacts, due to dirt, is entirely overcome, but with this system it is possible for more than two subscribers to be connected to the same line, in addition to which faults occurring on the multiple of the switchboard are more difficult to localise. Owing to the impossibility of inserting a plug, to cut off the rest of the switchboard one has to rely on the more delicate test of the differential receiver for the localisation of the fault. I am glad to notice the Post Office are adopting a similar common-battery system to those already adopted by the Company, and I trust that it will fulfil their expectations. With regard to Post Office automatic clearing, there is a very great difference between the old automatic system used by the Post Office in this town and a modern central-battery system. With the former I believe special batteries of large size have to be provided at the subscribers' offices, whereas in the modern system the energy is obtained from a central source, and

Mr. Wormull.

batteries at the subscribers' offices are entirely dispensed with. The question of extension circuits on the central-battery system does not properly come within the scope of my paper.

In reply to Mr. Turnbull, I believe my Company also find considerable difficulty in obtaining from English manufacturers apparatus of the necessary standard, but of late years a very great improvement is noticeable in this respect.

Mr. Gott has referred to stormy interviews with subscribers; but it is from complaints received from our subscribers that we are able to gauge the efficiency of our service, and we are therefore always pleased to interview a subscriber when he thinks he has cause for complaint.

MANCHESTER LOCAL SECTION.

THE CONSTRUCTION OF HIGH-TENSION CENTRAL STATION SWITCH-GEARS, WITH A COMPARISON OF BRITISH AND FOREIGN METHODS.

By HENRY W. CLOTHIER, Associate Member.

(Paper read at Meeting of Section, February 18, 1902.)

In the earlier years of our industry the switch-gear at a central station was regarded as a comparatively unimportant item. Electrical engineers gave prominence to the steam raising department, to the generating plant, and to the distributing system.

As time went on, however, the necessity of paying greater attention to the controlling arrangements became more evident. There are many instances on record where faulty switch-boards and connections thereon have introduced unforeseen disasters, which have included the loss of life, destruction by fire, and very frequently the discontinuance of the supply to the works and to the consumers. Such experiences as these are not only costly in themselves, but they have a tendency to check the growth of our industry by fostering a lack of confidence on the part of the general public in electricity as applied to power and lighting purposes.

The manufacture of switch-gear is now considered a distinct branch of electrical engineering, and the user recognises it as the centre of the whole system. He desires it to be an ornament to the station, on which special care is taken in the design, erection, and upkeep, so that it will be an example of utility, security, cleanliness, and general order to the rest of the equipment.

Engineering firms have established separate switch departments and they now compete with one another for contracts, the extent of which was unthought of but a few years ago in this country. The introduction of high-tension multi-phase power transmission schemes, with generating stations and numerous outlying sub-stations, equipped with converters, rotary or static, have created a demand for extensive controlling devices, which at the present time attain a value of from £30,000 to £70,000, according to the methods adopted by the several contractors.

It is the object of this paper to deal briefly with the broad outline of central station switch-gear practice, for alternating currents, and at the same time to meet the request of the Council of the Institution, to illustrate the main features in design of the apparatus produced in Germany as compared with our home productions.

The scope of this paper will be limited to a discussion on broad

principles rather than matters of detail, the way in which the components are assembled rather than the individual parts themselves; also since the limit of pressure in this country is about 11,000 volts, it will be of sufficient interest for the present to consider only those equipments which are in general use for that or lower voltages.

The functions of the switch-gear are, of course, familiar to you: but before proceeding, it will perhaps be well to recapitulate the chief considerations to be borne in mind by the designer :—

(1) The entire energy of the electric supply system is concentrated on the switch-gear and controlled therefrom, much as the heart controls the circulation of blood in the human body. It receives cable connections from the generating plant, and distributes the energy, transmitted by them, into the outgoing main feeders, which in their turn supply the districts covered by the system.

(2) It must embody arrangements for coupling or disconnecting any of the various members of the system, whether on the generating or the distributing side.

(3) It must be provided with devices which will isolate any part of the system on which a fault may arise, that would disturb the supply and cause damage to the affected part, or to any other part of the system.

(4) The apparatus must be capable of cutting off any machine or feeder, whether automatically or by hand, in such a way that no destructive arc will occur to damage the apparatus itself. It is also essential that the operation should not cause rises in potential sufficient to break down the insulation of the cables, or to injure any of the equipment on the system.

(5) It must be furnished with measuring instruments for indicating the pressure and current of the energy generated and distributed.

(6) Devices must be included for synchronising the generators, and for regulating them to keep up the supply at a constant potential to the consumers.

(7) The above parts must be assembled and constructed in a way that will afford the greatest security to the operator, and also to any other person who may be engaged on or near the gear, for repairs, adjustments, additions, for cleaning, or any other purpose. At the same time it should be so designed, that it is only necessary to rely upon a minimum amount of skill and caution on the part of the persons so engaged.

PART I.

NOTES ON GENERAL CONSTRUCTION.

The apparatus used, although of so many different designs, can be broadly classified under two very simple headings, viz.:—

SWITCH-GEARS WITH BACKS AND SWITCH-GEARS WITHOUT BACKS.

There are, of course, exceptions; but these headings serve the further purpose of generalising a distinction between the popular modern designs produced abroad and at home respectively. The

word "back" is used in its widest sense, to define the space occupied behind a board, or in a basement, cellar, or any place out of sight of the station operators. Constructions with backs can be sub-divided into the following types for the purposes of this description, *i.e.* :—

FLAT BOARD, MULTIPLE FRAME, CUBICLE, BASEMENT, AND KEYBOARD TYPES.

Those without backs will be described as :—

WALL SURFACE, HINGED PANEL, PILLAR AND CELLULAR TYPES.

Flat Board Type.—This very common construction consists of panels of marble or slate fixed in vertical positions by bolts or screws to a metal or wooden framework, which is tied to the wall and bolted to the floor. The board formed by these vertical slates divides a space off from the engine room, the space or "back" affording room and facilities for storing away and connecting up the several apparatus required. This type was used almost exclusively in early stations in this country for the small units which were then generally installed. Fig. 1 serves to illustrate the arrangement of a machine panel constructed on this principle. It will be seen that the switches, fuses, etc., were dangerously mounted on the front, with terminals projecting through to the back, joined up by cable connections. It is unnecessary to state that the risk to the operators of this type of board was recognised many years ago, and switchboards were made (notably the well-known Siemens and Lowrie Hall type) on which all high-tension parts

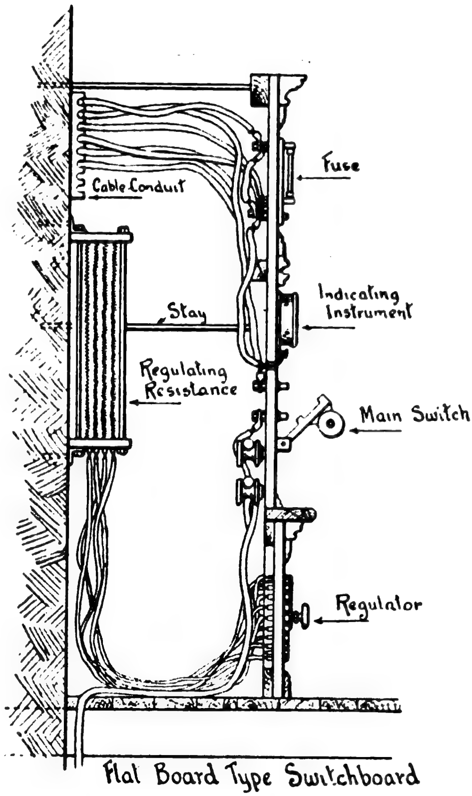


FIG. 1.

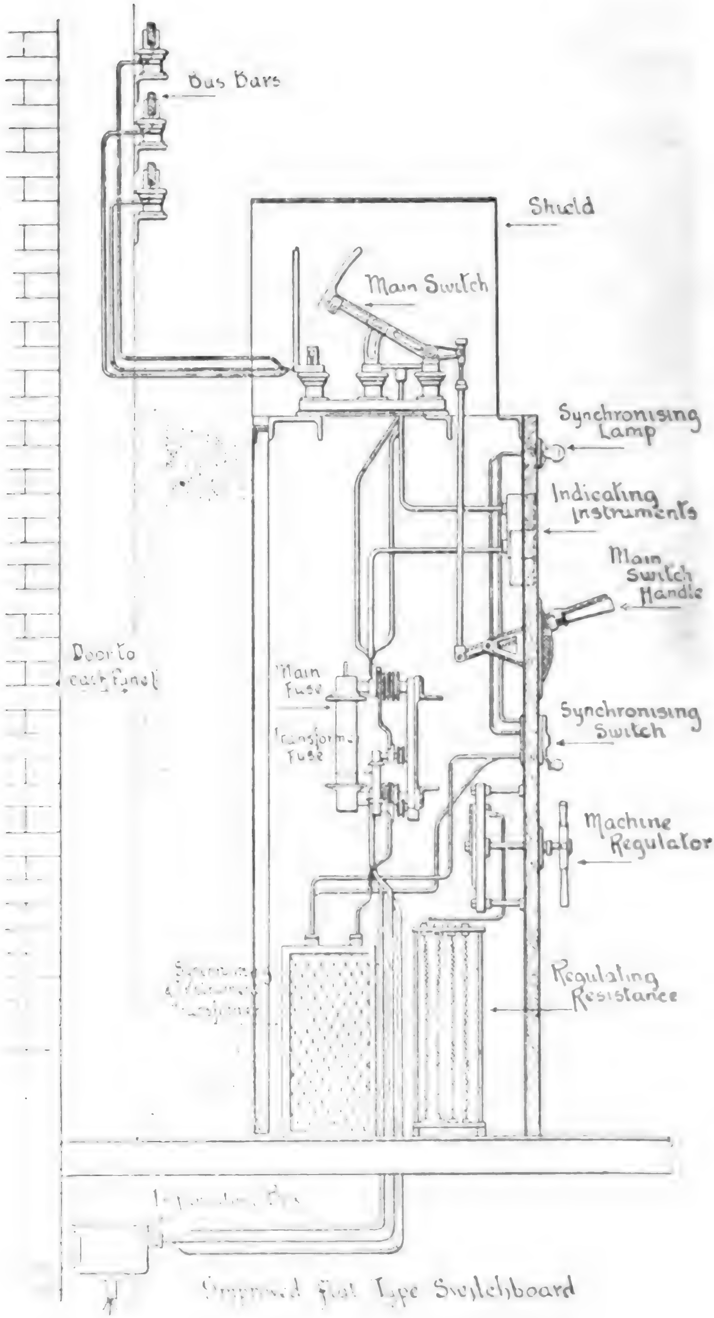

Bus Bars
Shield
Main Switch
Synchronising Lamp
Indicating Instruments
Main Switch Handle
Door to each Panel
Main Fuse
Transformer Fuse
Synchronising Switch
Machine Regulator
Regulating Resistance
Switchboard

FIG. 2.

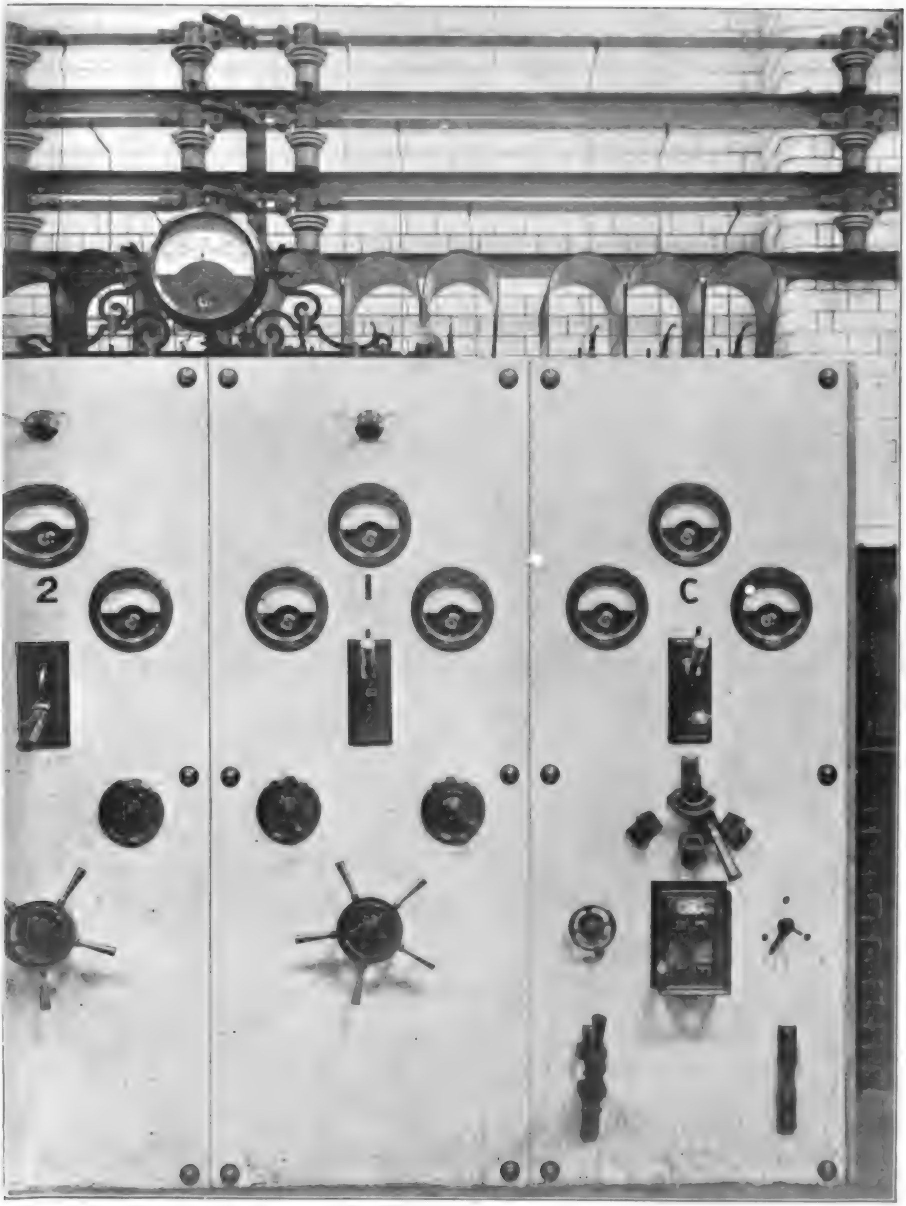


FIG. 3.

FIG. 4.

FIG. 5.

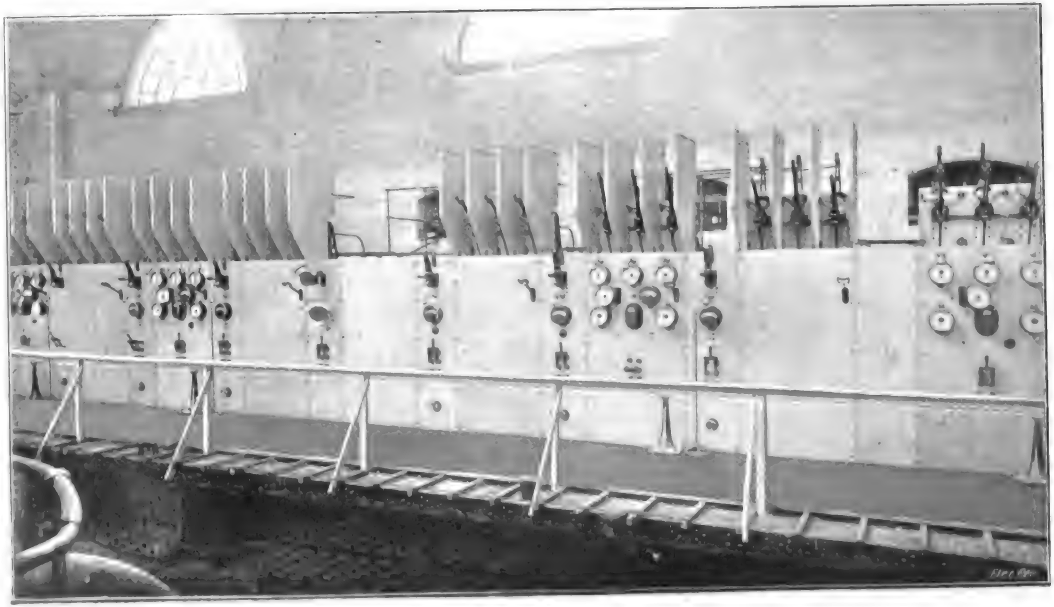


FIG. 6.

projecting through the front were covered by cups of porcelain or other insulating material, so that it was difficult to make accidental contact with them. But although the front of the board was then comparatively safe, the "backs" were always a source of anxiety. They were usually complicated by a chaos of inflammable cable connections, particularly where the board was designed for "independent" running on a double-pole system, in which each circuit panel was provided, in duplicate, with cable connections from each pole of each generator. The cable connections naturally increased the chances of fire, and also the extent of the damage in the event of a fire starting.

Many improvements have been made, such as covering up prominent parts of the frame with insulating material, by allowing very little space at the back, and by replacing the rubber cable connections between the terminals of the various appliances with carefully braided copper strips; but in regard to English practice it can be truly said that the type in question has caused so much trouble that it is now practically extinct among our home productions for high-tension alternating-current stations. No recent examples have been installed by home manufacturers, but on the other hand a large majority of the type originally installed in early supply systems have, at no small expense, been changed for switch-gears without backs, which will be described later.

Considering these experiences at stations generating at about 2,000 volts pressure, which has been a very usual voltage for lighting systems, one would not expect the larger power transmission schemes now becoming universal, generating at voltages from 5,000 to 7,000, to accept this type of board. Consequently, it is interesting to observe, as an example of Continental practice, the method adopted at the Kensington and Notting Hill Supply Company's station at Wood Lane, which reintroduced the type into this country. Fig. 2 represents a section through a 500 kilowatt 5,000 volt three-phase generator panel. Here live fittings are exposed only at the back and top, the front being quite free from any high-tension metal work. With the exception of the main switches and the 'bus-bars, the connections are contained in a cage of iron meshing, and, it is needless to add, that the main switch coupling the panel to the 'bus-bars must be locked off before any one is allowed to open the cage door, shown on the drawing. Figs. 3 and 4 clearly show the disposition of the instruments, as seen from the front through a hole in the marble slab; the main fuses of a tubular pattern mounted on insulators fixed to a metal frame, the levers operating the main switch, the regulating resistance at the base, and the cable connections which, though numerous, have been neatly arranged.

An American example of three-phase extra high-tension switchboard in use at the Glasgow Electric Tramways generating station may be termed a modification of the flatboard type. Figs. 5 and 6 represent front and back views of this 6,500 volt dynamo board. In the former view the low-tension connections to the instruments on the dynamo panel can be traced on the panel to the left. The 'bus-bars seen in the illustrations are the 100 volt exciter connections. No attempt at covering high-tension fittings has been made, but, as a precaution in

design, all high-tension conductors are placed at the top above the heavy cross girders seen in Fig. 6, at a height not less than 10 ft. from the floor level. All measuring instruments mounted on the front are of the transformer type, the transformers being also mounted out of reach from the floor level. The main switches seen in Fig. 6 are a carbon break type, and are arranged in compartments between marble slabs.

It is unnecessary to cite the many Continental and American switchboard constructions and the numerous methods of arranging details to show that, abroad, the "flat-board" type is very commonly used for high and extra high voltages. The main idea in the design of these boards has been to make them safe to the operators from the front, and presumably to expect a high degree of skill and caution from those who may be engaged on any other part of the gear.

The Multi-Frame Type.—This construction, shown in Fig. 16, consists of a marble front mounted in a metal frame carrying switch handles and instruments similar to the flat-board type, but the back of these panels is used only for the exciter connections and low-tension instruments. A separate and distinct skeleton frame-work with a clear space around it and a passage between it and the front frame, carries all high-tension conductors, including fuses, switches, 'bus-bar, instruments, transformers, etc. A somewhat similar type, constructed by the Allgemeine Co., is in use at Berlin for their three-phase system. Although this construction covers a greater floor space than usually convenient, it has its advantages when compared with the previous type, in that the high-tension conductors are spread over a larger surface, and there is room enough to get at them from all sides.

Cubicle Type.—For feeder switch-gear the Westinghouse cubicle type, as applied at Glasgow, should be mentioned. The construction shown on Fig. 7 consists of sets of four complete three-phase panels placed back to back in two pairs, each set of four panels enclosing a space, forming as it were a chamber, on the walls of which are mounted the main cable junction-boxes and the low-tension instrument connections, etc. Like the dynamo board at the same station no exposed high-tension connections are within reach from the floor level; but they are visible on the illustration above a horizontal marble slab, which forms a roof to the chamber. This useful method splits up the usual back into a number of chambers, which can be readily inspected by the attendant in passing from one section to another.

Basement Type.—There are several types of supply station apparatus on which the dynamo or circuit high-tension gear (sometimes both) is mounted in compartments below and above (generally below) the attendant's platform. The switches are controlled either by chain gear or by a mechanical arrangement of levers and links. The Helios switch-gear at Dresden is a notable instance of the latter. Fig. 8 represents a section through a dynamo panel showing a plug type mercury contact main switch controlled by a system of railway signalling levers from the platform. Each machine is furnished with other similar levers for regulating, synchronising, etc. Directly behind these levers is a metal column containing all instruments and connections thereto.

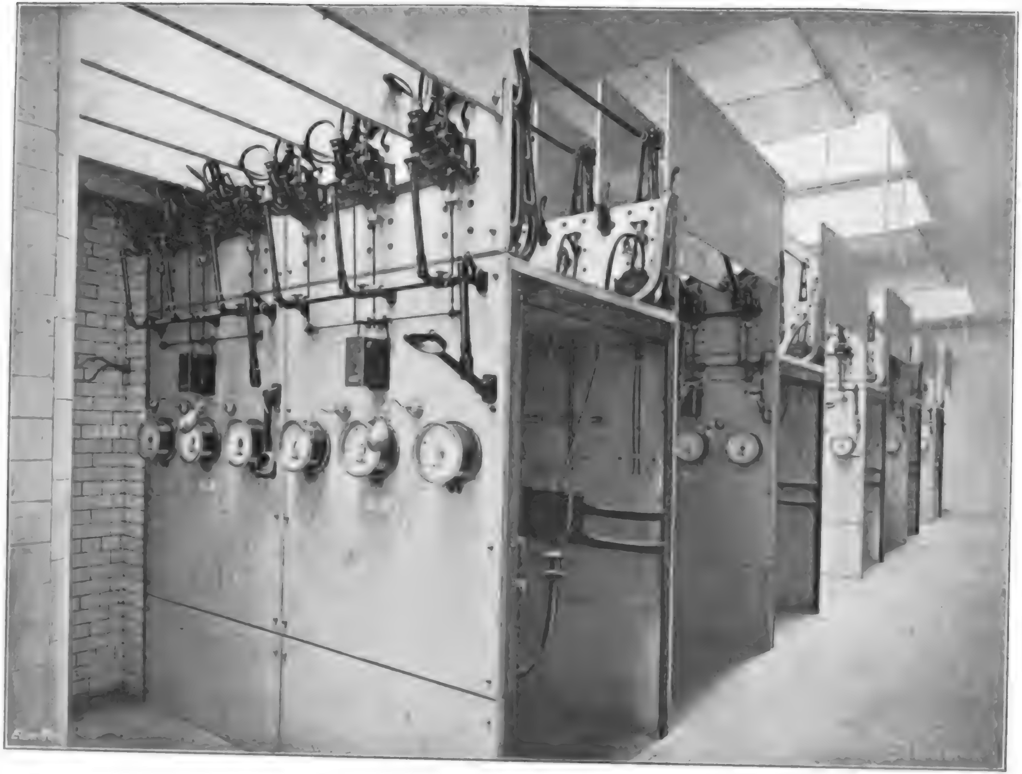
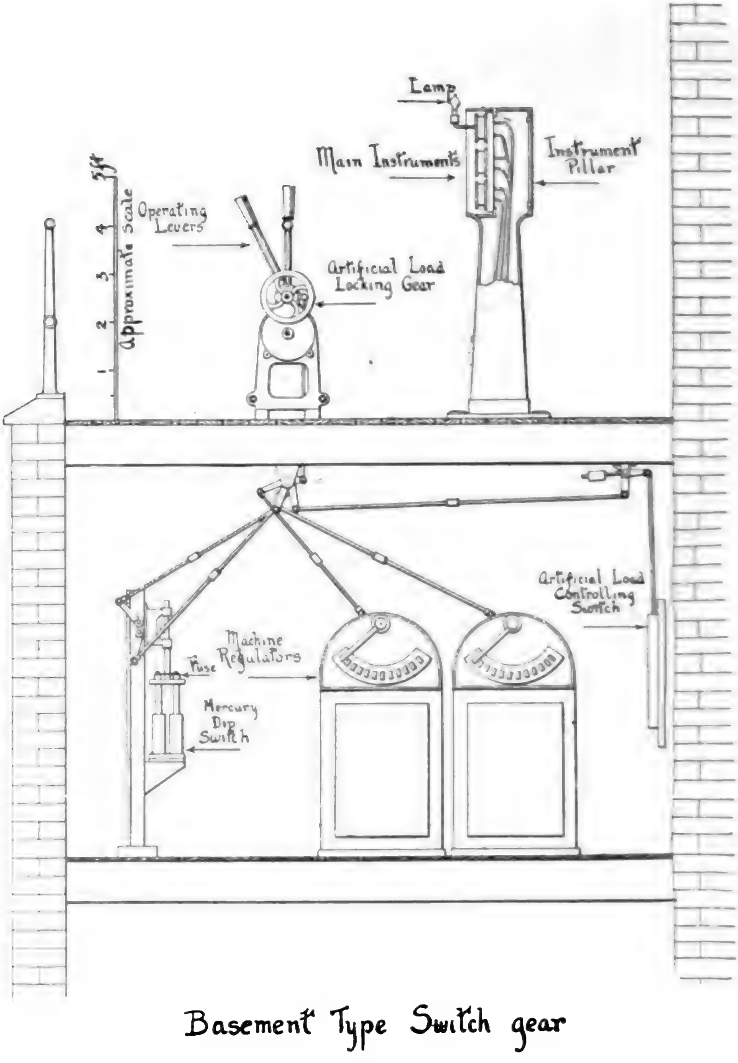
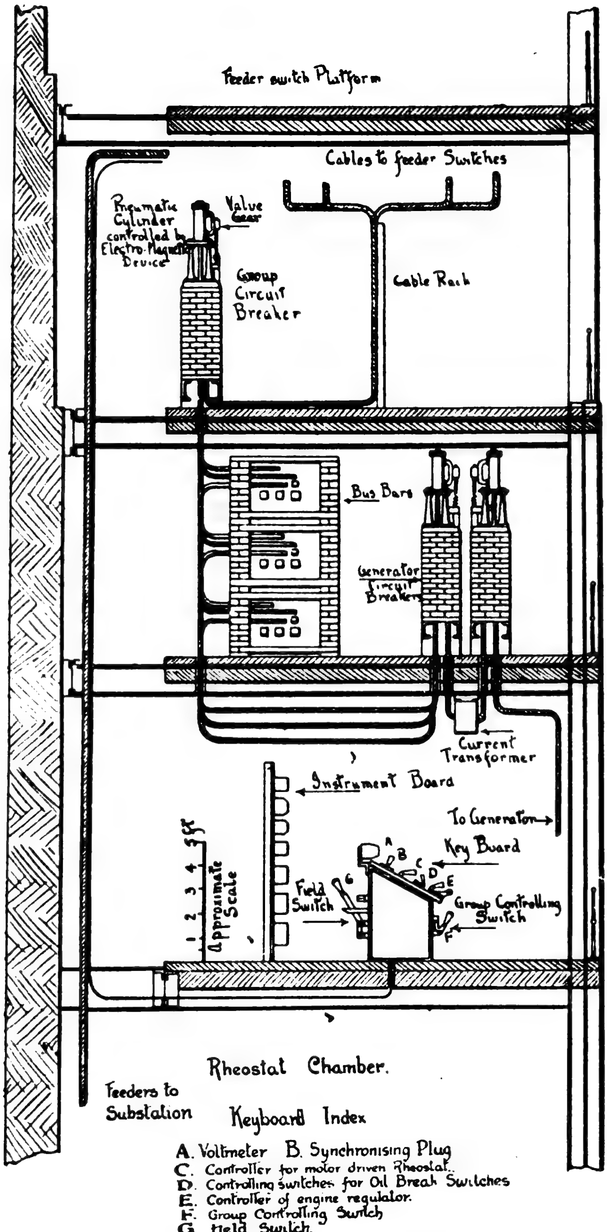


FIG. 7.



Basement Type Switch gear

FIG. 8.



Keyboard Type Switch Gear.

FIG. 9.

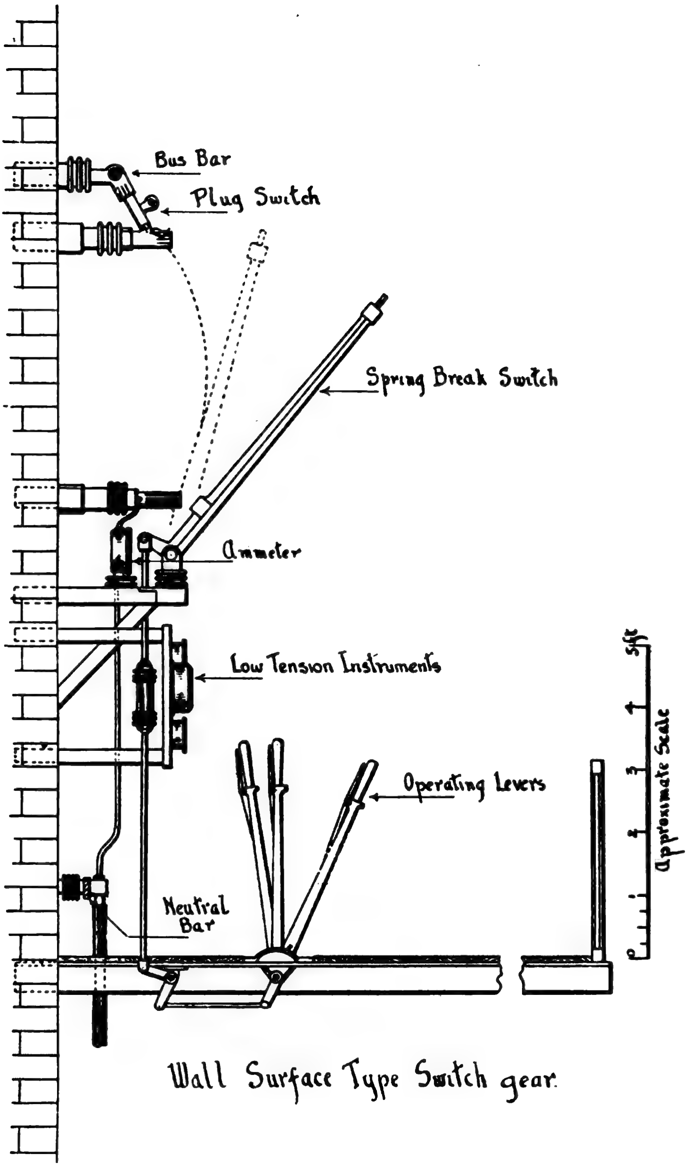
The Keyboard Type.—Fig. 9 represents a section through the platforms and galleries showing the relative positions of the main parts of the construction, an example of which is to be seen in the generating station of the Metropolitan Street Railway Co., at New York, where switch-gear is at present installed for controlling eight 3,500 kilowatt units at 6,600 volts, three-phase. On the first gallery will be seen a keyboard, with small switch handles arranged in such order as to represent a diagram of connections. An instrument panel is supported on a metal framework behind the keyboard. The main dynamo switches, in duplicate (as a precaution against one failing to operate), are supported on a second gallery, which also carries the main 'bus-bars covered by a brickwork erection. The switches are controlled by a pneumatic cylinder, the valves being operated by electric relays from the keyboard on the gallery below. Later designs replace the pneumatic cylinders by a system of electric motors. Whether they find it is satisfactory to have such important work dependent on the delicate pneumatic and electric auxiliary gear, irrespective of the initial cost of this design, I am not able to say. But obviously this objection is met by the method of duplicating the switches in series with each machine.

Switch-gear without Backs.

Wall Surface.—Fig. 10 illustrates the type of switch-gear constructed at Deptford in 1888, the first station in this country where power transmission on a commercial scale was attempted. Although in designing this station for 10,000 volts Mr. Ferranti was at least ten years before the times, yet the switch-gear then installed has certain advantages not to be found in many of the modern designs.

It will be seen from the drawing that the general idea was to support the extra high-tension conductors on porcelain or ebonite insulators mounted directly on to the surface of one of the walls of the station. Thus all connections were visible and easily traced by a person standing on the platform. To prevent arcing between adjacent conductors a liberal area of wall was occupied, and slate or marble partitions were set here and there in the wall at places where the clearances dividing parts of different potential were limited. Each panel can be isolated from the main inner 'bus-bar by the removal of a plug with the aid of a long insulated hook. The main switches are of a long spring-break type, the machines being entirely controlled by levers mounted on the platform. Thus, although the operator has always a clear view of all his connections, yet they are so far out of his reach that he cannot make accidental contact with them in the ordinary course of his duties.

Pillar Type.—This type also deserves a place in the front rank of English designs, the best known being that designed by Mr. Raworth many years ago and constructed by the Brush Co. There was one complete unit of switches, instruments, etc., for each generating plant, enclosed in a pillar as shown in Fig. 11. The illustration in question represents a view of a dynamo pillar with water-break switch at the top controlled by a handle protruding from the front at a lower level.



Bus Bar
Plug Switch
Spring Break Switch
Ammeter
Low Tension Instruments
Operating Levers
Neutral Bar
Approximate Scale
5ft
4
3
2
1
0
Wall Surface Type Switch gear.

FIG. 10.

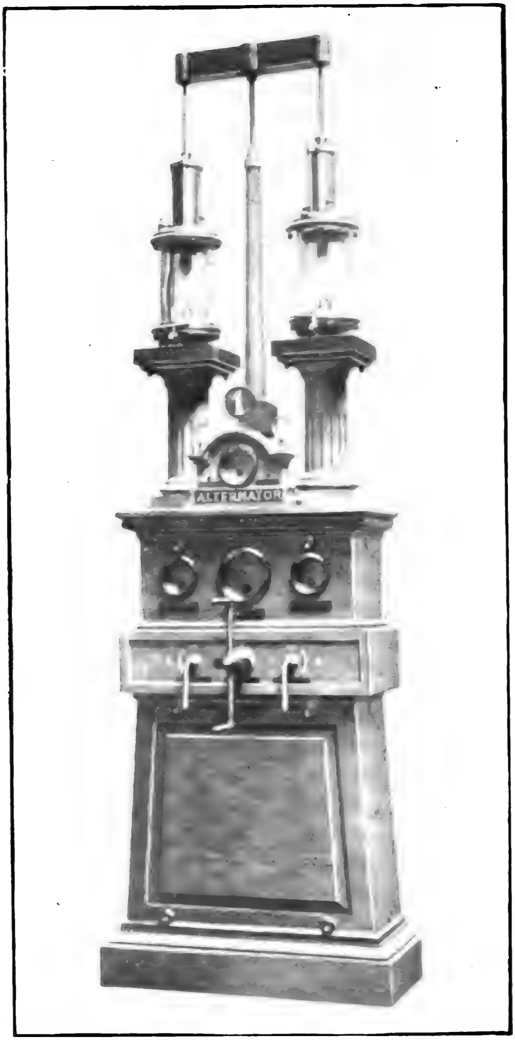
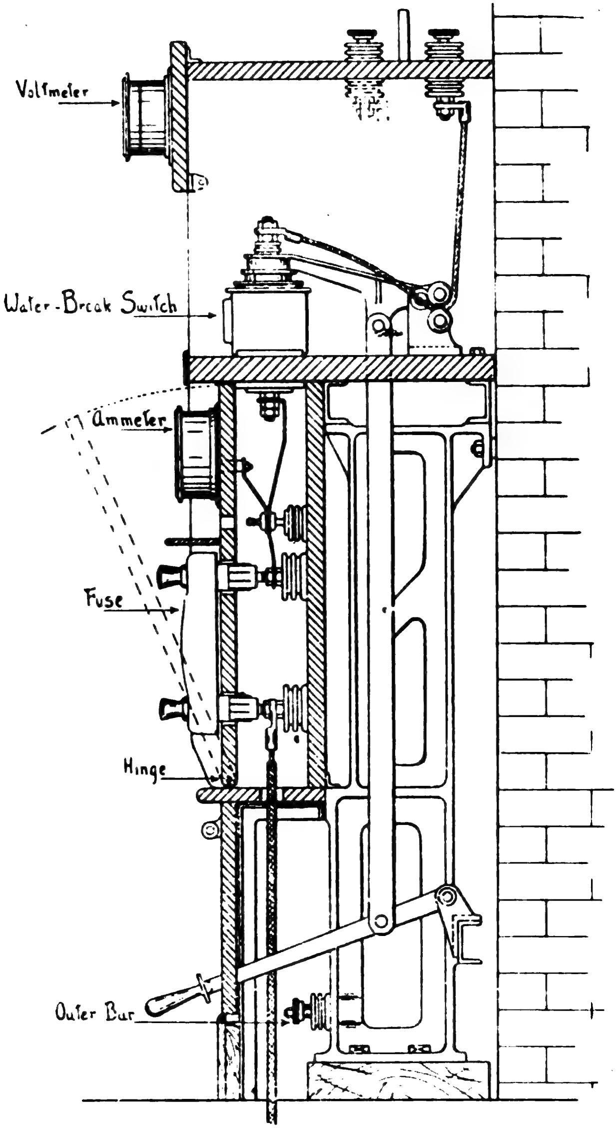


FIG. 11.



Hinged Panel Type Switch Gear

FIG. 12.

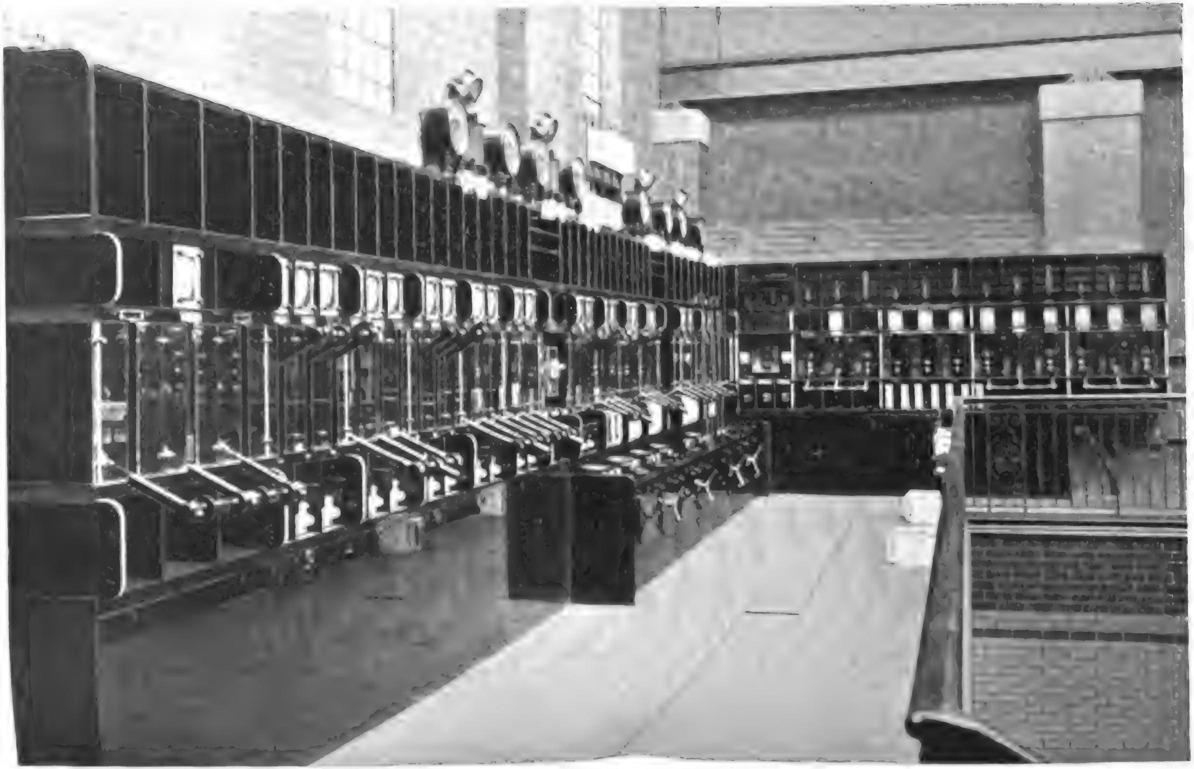


FIG. 13.

The merits of the design, however, have not been confirmed in actual practice. In fact, as stations grew in size the system appears to have been found inconvenient and costly, with the result that the pillar type has become almost obsolete in England.

Hinged Panel.—This ingenious construction, invented by Mr. Cowan, consists of an arrangement by which the vertical panels supporting the high-tension switches, instruments, and fuses can be hinged from the bottom. The operation of unhinging disconnects the entire panel from the 'bus-bars, and affords ready access to the connections. This type, though very serviceable for small units, becomes difficult in construction when larger units are to be controlled; but Fig. 12 shows the method applied to meet the requirements of larger units by mounting the switch solidly at the top. The hinged panel below contains the other fittings. It is evident from the illustration (Fig. 12) that, although there is still an interval between the flat panel and the wall, this space is so reduced that there is no chance, even if there were the necessity, for any one to go behind.

Cellular Type.—This construction, better known as the Ferranti switch-gear, was first installed in Portsmouth in 1894 for 2,000 volts, and it has since been extensively, and indeed for the last three or four years almost exclusively, adopted throughout this country on 2,000 or 3,000 volt single-phase systems. Referring to Figs. 13 and 14, it will be seen that the framework consists of a number of heavy slabs of insulating material grouted into the station wall and protruding therefrom. The spaces between them are divided off into a number of cells by vertical division plates, also of insulating material, made to slide into grooves cut in the horizontal slabs. Porcelain insulators are mounted deep into these cells or recesses, which carry the high-tension conductors and several metal fittings for receiving the switches, fuses, instruments, etc.

This arrangement entirely eliminates the space at the back, common to the types before mentioned. While all the connections and conductors are visible, and easily traced from the front, they are so shielded by the cellular construction of insulating material that it is, to all intents, impossible to make accidental contact with any two metal parts of different potential at the same time. Moreover, the constructional framework is made up of non-inflammable material without resorting to a metal frame, thus affording great advantages both as to insulation and immunity from fire or accidents due to shocks. Thanks to this security in design, the record of this type of switch-gear has not been marred by the occurrence of any serious or fatal accident. This is striking evidence when one considers that there are more cellular type high-tension alternating-current gears working in this country than all other kinds totalled together.

Fig. 15 shows a section through a 3,000 kilowatt three-phase generator panel. The 'bus-bars will be seen at the top. Each panel is furnished with a plug by which it can be readily isolated. All high-tension instruments, switches, and fuses are made to plug into contacts, and fixed in such a way that they can be quickly withdrawn even while the rest of the apparatus is "live." On all feeder panels the fuses are

provided with duplicate contacts for this purpose. The drawing shows the position of the regulating table, field switch, exciting current ammeter, and resistance, which are mounted separately, but in a line with the high-tension panels.

Another feature of this construction is the absolute absence of cable connections between the various components and the mechanical means adopted to replace them; each high-tension part is contained in a complete cell, and so divided from any other part of differing potential.

This concludes the description of the various constructions. There are, of course, others invented and used for alternating-current switch-gear, but the foregoing are typical of the most important generic designs which have been tried and put to practical use.

'Bus-bars.—Complexity must inevitably give way to simplicity in all apparatus. In no part of a central station is this axiom more applicable than in the arrangement of the 'bus-bars, which form the foundation of the connections. Numerous ingenious and complicated methods exist, involving the duplication of parts, multiple 'bus-bars, change-over switches, cross connections and other elaborate provisions which seem to allow for every emergency. However, simple as they may be made to look on paper, in practice they tend to increase the difficulty of supervision and chances of mistakes. The confusion may be modified by complex systems of interlocking devices, but for perfection in design these should be unnecessary. There should be no alternative ways of operating any part. Given one way the attendant cannot go wrong. For this reason alone, irrespective of the many other advantages, such as economy in running, uniform distribution of the load, etc., it is preferable to parallel all generators to one common set of 'bus-bars. The arrangement of 'bus-bars has such an important bearing upon the switch-gear construction that it is opportune to consider some of the other methods as illustrated by diagrams on Figs. 17 and 18, which, to save a repetition of lines, have been drawn to represent the connection of one pole only. The network involved by them on three-phase systems can be imagined. Each diagram represents the high-tension connections for four generators and eight outgoing feeders. It is interesting to note from them how a simple construction can be converted into a complicated one.

PART II.

COMPARATIVE NOTES ON BRITISH AND GERMAN SWITCH-GEARS.

In these notes it is not the intention to criticise, but to assemble the main features and essential points of difference in general design, in order that fair conclusions may be drawn from them, and from the discussion, which the author hopes may tend to improve not only the imported material but also the productions of this country. It must be understood that the methods of Germany herein mentioned are those which appeared to predominate among the extensive works and supply stations visited during the recent tour of the members of this Institution. It is only natural to conclude that the works exemplified the most modern and approved methods. The standard of British

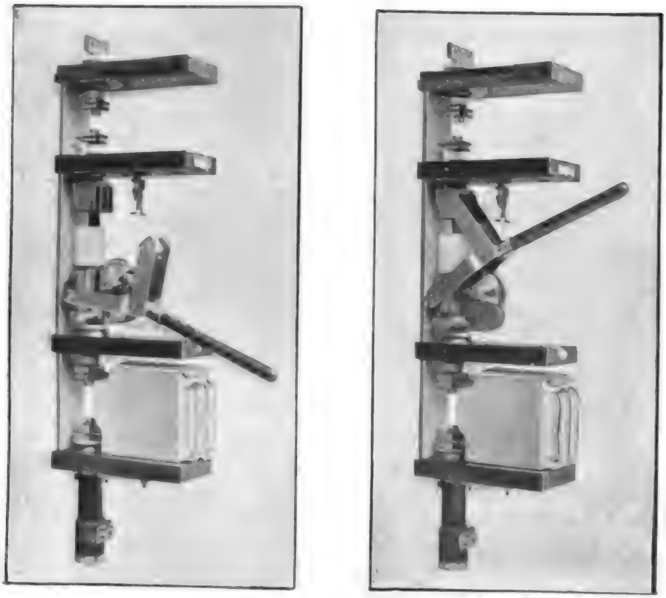
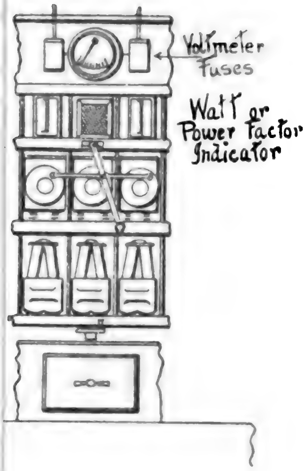
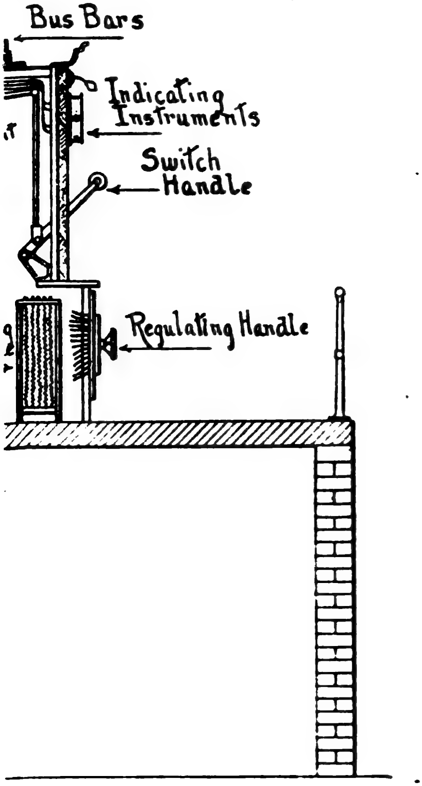


FIG. 14.


Voltmeter
Fuses
Watt or
Power Factor
Indicator

tch



Bus Bars
Indicating Instruments
Switch Handle
Regulating Handle

h Gear

designs considered will be the cellular type which has been installed in the majority of stations in this country.

Figs. 15 and 16 have been drawn to the same scale to represent a comparison of the typical switch-gears of both countries. The views are intended to illustrate a 3,000 kw. generator panel for a three-phase system at about 6,000 volts.

General Construction.—In this respect the description in the first part of this paper will point decisively to the fact that whereas, in this country, great endeavours have been made to render all parts of the gear visible and yet inaccessible by accident, in Germany the aim has been to attend only to the safety of the front portion of the construction. The gears are of the type with backs, and are designed on the "flat-board," "basement," and "multi-frame" principles; bare 'bus-bars are usually mounted on insulators without any form of covering, and no attempt is made to shield other live fittings which are mounted at the back. The intermingling of these fittings with the metal framework is the converse of the policy taught by our experience, which is to have no back and to avoid the use of metal framework near high-tension conductors. Moreover, the absence of straggling cable, and strip connections, between the component parts of the gear is very apparent on the cellular construction as compared with the foreign boards with backs.

The Space Occupied by the switch-gear is often an important consideration in planning a central station. In this respect it is worth noting that the "cellular type" occupies about one-third the floor space as compared with the other types, and for the same number of machine, circuit, and inter-connecting panels, about two-thirds the length of platform required by a well-designed "multi-frame gear."

Switches.—In Germany the main switches are invariably operated from handles projecting through the marble fronts. Oil-break switches contained in cast-iron boxes are used, but the general practice is to use those designed to open with a slow movement, allowing an arc to draw out, flare and die away gradually, on the principle of the Siemens and Halske lightning arrester. This method is also directly contrary to the principle of quick break devices for suppressing the arc, and the more efficient oil-break switches which have proved successful in this country.

The High-tension Fuse most extensively used in Germany is not unlike the well-known Bates fuse, consisting of an open ended tube of porcelain, ambroin, stabilit, or similar insulating material, with plug terminals at each end. The fuse wire of copper or alloy is threaded through the tube and clamped by screws and plates or soldered to the terminals. For potentials of 2,000 to 10,000 volts the length of these tubes varies between 8 inches and 15 inches. Several fine wires are connected in parallel for the higher voltages, each wire being enclosed in a separate internal tube or otherwise partitioned by insulating material, so that each wire has a column of air to itself. Unlike the Bates fuse, there is no handle moulded with the tube, but flanges are provided at the ends, and moreover, in most cases, it is customary to have a long pair of wooden tongs close by the switch-gear with which

any fuses can be clutched while the operator is at a safe distance from it. Considering the massive tube fuses used at Deptford and Willesden —they are from four to five feet long—and also the expensive designs, such as the oil-break fuses of home manufacture, it would appear that either we over-estimate the destructive effects caused in breaking high-tension circuits, or else the necessity of blowing a fuse without destroying the fuse-holder is not considered as a matter of importance in Germany. The variation in size and initial cost of the respective designs is very pronounced.

It is very common in German practice to construct high-tension switchboards without fuses or automatic devices of any kind in circuit with the alternators, and to have plug fuses on the outgoing feeders, but no switches on these circuits. The fuses in such cases are placed in cellars or in basements away from the station attendants. There is thus no way of breaking a load on a feeder circuit other than by blowing its fuse. The visible switch-gear in these stations is only that required for the control of the machines whilst under normal conditions. We were informed in one important station in Berlin that one man was never sent alone into the cellar or basement, but, for safety, was always accompanied by another to look after him.

There are many points of difference in the instruments used on high-tension switch-gears. Electrostatic voltmeters, almost universally used in this country, give way in Germany to electromagnetic or hot wire voltmeters connected to the secondaries of transformers. But in a few instances where electrostatic instruments are used it is instructive to us to note that the cases are made of insulating material, and the difficulty common to alternating current systems of sparking over, due to rises in potential, has been obviated by covering the fixed cells with a layer of insulating material such as mica shellaced over, thus forming an efficient insulating shield between the cells and the moving vane. For further protection a resistance is connected in series with the fuses. Unlike our Kelvin, and Ayrton and Mather voltmeters, the German electrostatic instrument is not usually fitted with a spark gap. The scales, however, of these instruments—taken collectively—are not so

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DESCRIPTION OF FIGURE 17.

(A) All machines and feeders connected to one common 'bus-bar.
(B) The system is divided into two halves, with one centre machine and circuit on each side, and inter-connector switch in the middle, by which the two halves can be separated or paralleled.
(C) The system adopted at Croydon and Edinburgh with duplicate 'bus-bars, synchronising gear, feeder and dynamo switches.
(D) Another arrangement with duplicate 'bus-bars, but without duplicating the switches, inter-connector switch being provided to parallel the bars together.
(E) Modification of (D) with three 'bus-bars, as adopted at Huddersfield.
(F) Representing the method of arranging 'bus-bars at Glasgow Central Tramway Station. The system is divided into complete sections by inter-connector switches, so that, if necessary, any machine can run separately on to one section of feeders.

The diagrams do not represent the actual number of machines in use at places mentioned, but by way of comparison they denote the methods as applied to four machines and eight feeders. They also serve to show the relative space occupied by these arrangements.

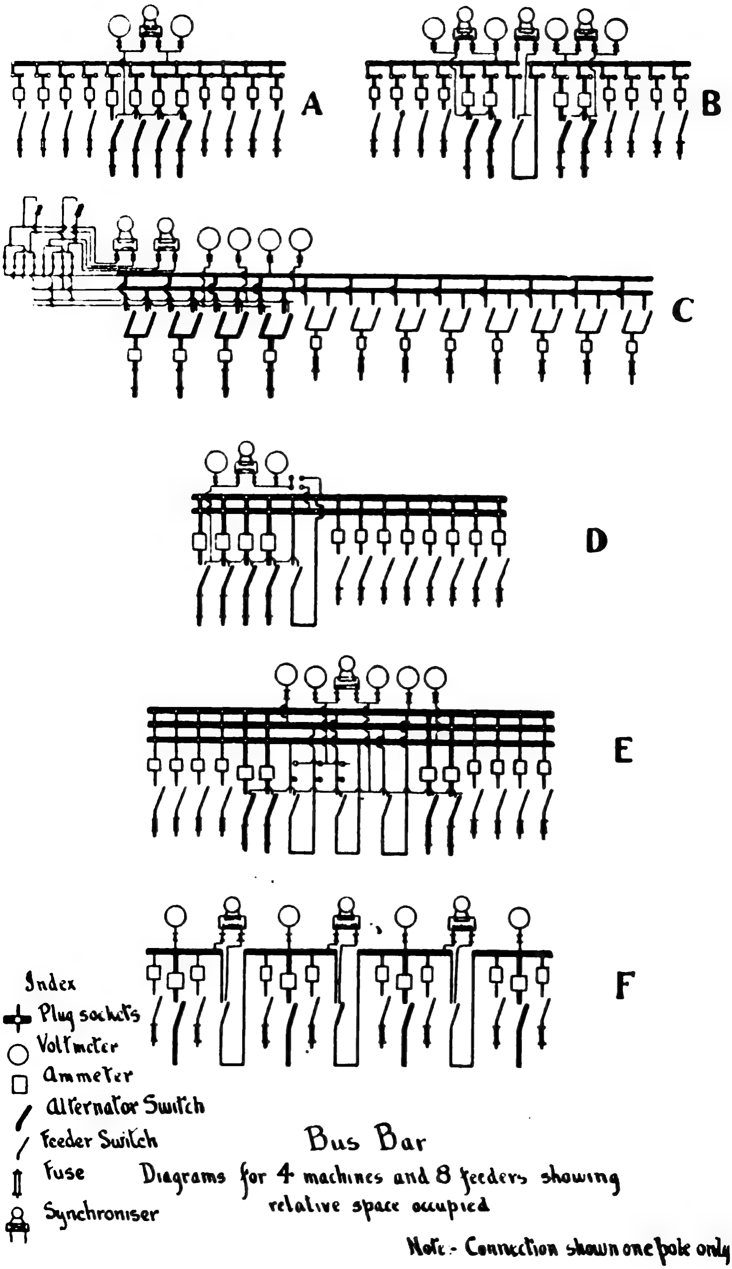
A
B
C
D
E
F
Index
Plug sockets
Voltmeter
Ammeter
Alternator Switch
Feeder Switch
Fuse
Synchroniser
Bus Bar
Diagrams for 4 machines and 8 feeders showing
relative space occupied
Note:- Connection shown one pole only

FIG. 17.

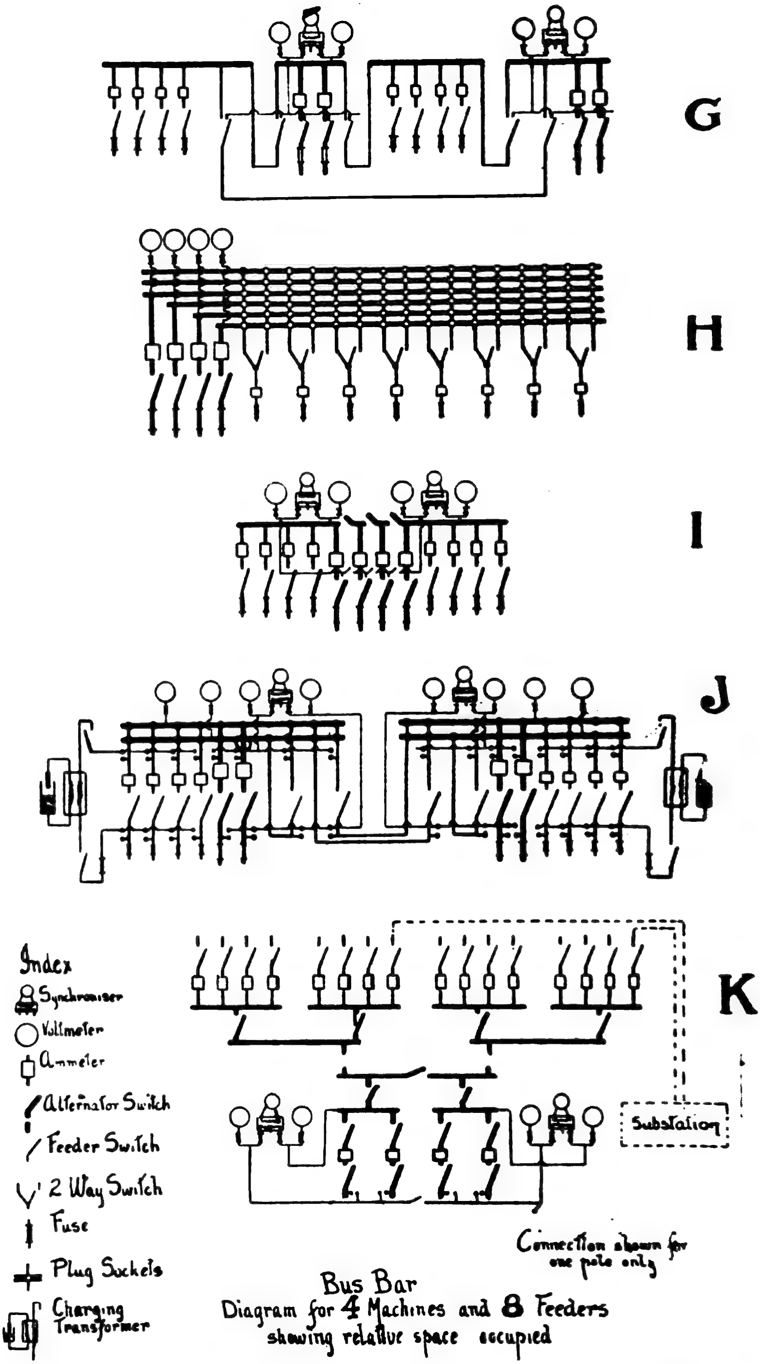
G
H
I
J
K
Index
Synchroniser
Voltmeter
Ammeter
Alternator Switch
Feeder Switch
2 Way Switch
Fuse
Plug Sockets
Charging Transformer
Substation
Connection shown for one pole only
Bus Bar
Diagram for 4 Machines and 8 Feeders
showing relative space occupied

FIG. 18.

open and boldly marked as on our patterns. Accustomed as we are to our long ranged voltmeters and ammeters, of both dial and edgewise patterns, the instruments in common use in German central stations appear to us somewhat small, and the scales seem to require close inspection to read them.

All possible means whereby connections and apparatus can be reduced, without affecting the utility of the whole, should be taken advantage of. With this in view there is something to the credit of the home designs in the method of using one common synchroniser, and incoming machine voltmeter, instead of complicating the system by using separate synchronising transformers and voltmeters for each machine. As an example of the former, the Ferranti method is to make contact automatically with a common synchronising bar (or pair of bars for multi-phase system), while the main dynamo switch is in a "half-cock" position. This arrangement has the advantage of simplicity in construction and also in working, as compared with the latter method which entails the provision of separate plugs or switches on each machine panel.

There are many other details of more or less importance where the best switch-gear practice of the two countries differs, such as the method of connecting to the 'bus-bars and of isolating panels by the use of 'bus-bar plugs, the provisions for receiving cables, and for removing instruments and other parts of the gear safely and quickly without the use of special tools. These details have perhaps been more carefully dealt with in our best British designs than has been considered necessary in Germany. On the other hand, we may have to learn something concerning the methods of economy in design and production by which passable results can be obtained with a minimum

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DESCRIPTION OF FIGURE 18.

(G) Represents connections of Kensington and Notting Hill Supply Station, where the complete switchboard is divided into four sections, including two sections for machines and two for feeders, with a ring main system of 'bus-bars and switches, by which either of the dynamo or feeder sections can be run together respectively.

(H) Connections for the obsolete system of independent running, where any generator can be run separately on to any number of feeders.

(I) Suggested 'bus-bar arrangement, where it is necessary to divide the system into two sections, as for tramway and lighting purposes. The two machines in the middle can be connected to either traction or lighting 'bus-bars by knife switches shown on the 'bus-bars.

(J) Arrangement of connections for a switchboard with duplicate 'bus-bars for tramway and lighting purposes respectively, a system of inter-connector switches being shown, by which either of the four sets of 'bus-bars installed can be synchronised or coupled. The drawing shows the method of connecting the cable-charging device.

(K) Is to illustrate the switchboard connections on the basis of the design used for the Metropolitan Street Railway Co., New York, where the system is divided into two sections, the feeders being arranged in groups. Each sub-station is connected by a feeder, or feeders, from either side of the central station switch-gear.

The diagrams do not represent the actual number of machines in use at places mentioned, but by way of comparison they denote the methods as applied to four machines and eight feeders. They also serve to show the relative space occupied by these arrangements.

expenditure in material and labour. But it is difficult to know where to draw the line in cutting down material and cheapening designs, because it is of such vital importance that, for apparatus on which so much depends, the efficiency must not be sacrificed for economy in design.

To sum up, the main and great difference rests in the principles of construction; the details follow in sequence and are to a certain degree dependent upon them.

Conclusion.

It will form a fitting conclusion to this paper to consider, without taking up too much time, the absolute requirements for one of the common systems of transmission. The single-phase switch-gear has become practically standardised, but the three-phase switch-gear for 6,000 to 10,000 volts introduces many problems for discussion.

The first question to decide is the 'bus-bar arrangement. The diagrams on Figs. 17 and 18 show many methods, but of these, provided the switch-gear is reliable, there is none more suitable than the simplest (represented in diagram A) for any number of machines of modern design. There are, however, cases where it may be deemed advisable to split up the station plant into sections. For example, in Manchester, it is proposed to run one set of generators on the traction load and another set on the lighting load. It would be interesting to know what effect the fluctuation of the traction load would produce on the lighting load if the two systems were run in parallel, assuming that motor generators, or rotaries, convert the high-tension alternating current to a divided continuous current supply for the consumers. It is quite possible that there is no need to have separate high-tension traction and lighting 'bus-bars at all, then it will be more economical and convenient to run every machine on to one common set of 'bus-bars; means being provided so that any generator or feeder panel can be readily isolated for adjustment, repairs, or cleaning purposes.

With a balanced load only one ammeter is essential on a three-phase panel, but provision should be made to enable this or other ammeters to be used occasionally for reading the current on any or all three phases.

There is no doubt that it is the best practice to supply fuses with duplicate contacts to each phase on the feeder panels. But for generators the conditions are different; with two or three alternators running in parallel, fuses have sometimes given trouble by opening the circuit of all the machines when a fault has occurred on one only. Reverse current automatic switches have been made to meet this objection, but complications are involved thereby, which introduce an element of uncertainty in action under emergencies. Another way of dealing with the question is to have no fuses or automatic devices on the generators. Modern alternators will stand a short for a few minutes, or at least for sufficient time to blow the feeder fuse if the fault is on the mains, or if the fault is on the generator, to enable the attendant to isolate the defect.

Machine and feeder switches must be of selected pattern which will

open circuit without enabling a rise in potential to occur, and without causing injury to the switch contacts when used for breaking, not only the rated capacity of the circuit, but under the more severe conditions to which they are likely to be subjected when emergencies occur. It must be remembered that tests which have been carried out in this country, and on a larger scale with higher voltages in America,[1] show that the maintenance of an arc in open air, even for a short period, is liable to produce resonance effects, and high voltage oscillations, equal to two or three times the normal potential of the system. Whereas it would seem from tests carried out at the same time that excessive rises in potential are not experienced with oil-break switches. Spark gaps which will arc across when the pressure rises above the normal can be fitted to the 'bus-bars or to the cable, but the switch-gear should be constructed to avoid the necessity of these devices which are likely to irritate the system and reduce the degree of safety by bringing conductors of differing potential close together on one apparatus.

The capacity of the feeder cable has an important bearing on the design of feeder switch-gear, due to the rise in potential occasioned by switching on and off a long length of main with capacity. Charging devices which will operate in conjunction with feeder switches are necessary in such cases.

We have not had much experience with power-factor indicators, but provided a reliable instrument can be obtained to read the lag or lead of an alternate-current supply, it would be a serviceable, though not essential addition to the feeder panel in that it would to some extent communicate to the central station the condition of the load and the regulation of the motor generators at the sub-stations.

With regard to recording or registering wattmeters, the simplest practice is to mount them between the feeder and generator 'bus-bars so that they will register the total energy generated by the entire plant. Indicating wattmeters can be mounted on the generator panels in the same way that the power-factor indicators are attached to the feeder panels (see Figs. 15 and 16). But given reliable ammeters it is not difficult to estimate the output of the alternators near enough for all practical purposes, and so where initial cost is of moment both indicating wattmeters and power-factor indicators can be dispensed with.

The generator panels have obviously to include synchronising devices, and a regulating table containing field switches, field current indicators and regulating resistances. It is only necessary to add the 'bus-bar voltmeters and possibly a panel for an auxiliary motor generator to fulfil the principal requirements of a complete three-phase central station switch-gear.

In view of the general tendency towards standardisation in the designs of any apparatus manufactured and used throughout the world for one common purpose, it is evident that many designs at present in vogue will disappear in favour of a switch-gear which will be the out-

[1] Recorded in a paper read by E. W. Rice, jun., before the American I. E. E., Buffalo, August 22, 1901.

come of the experience to be gained in the immediate future. On what principles will the switch-gear of the future be based? The author hopes this paper will evoke suggestions that will help to solve this problem and so be a guide to our switch-gear designers.

Mr. Cowan. Mr. E. W. COWAN opened the discussion by expressing satisfaction with the more mechanical style which characterised the design of switches and gear generally found in well-equipped power-stations of to-day. The old style of board with a passage at the back had not disappeared any too quickly. The passages were dangerous traps for the attendants, and the space was often very costly and inconvenient to obtain. Few people realised the danger arising from the mixture of inflammable materials, fuses, line-terminals, etc., that were hidden away at the back of these boards, and the difficulties of making repairs were greatly increased. In one station in Germany he was unable to discover the position of the high-tension fuses, and upon inquiry learnt that they were in the basement. Being desirous of inspecting them, he persuaded one of the officials in charge to permit him to go below. The passage-way to these fuses was blocked by "locked" doors on each of which was an unpronounceable legend, and a large and very vivid flash of lightning to awe any one who approached. His efforts, however, disclosed the fact that in Germany high-tension fuses are looked upon as things that are best kept away as far as possible. It took some twenty minutes to get to them by reason of the protecting cordon of locked doors, etc. His inspection of the low-tension switches as shown at Paris Exhibition revealed that they were all of the slow-breaking type which would certainly not open circuit carrying normal current at 500 or even 250 volts. They were mounted on well-finished frames, however, in the construction of which no timber was used. Foreign switch-gear was evidently cheap to manufacture, as had been proved lately by some of the tenders against which they had to compete. Turning to the question of the arcing at switches, Mr. Cowan remarked that arcs were nature's safety valves permitting the pressure to fall slowly. Switches which broke under oil or water were too abrupt for direct-current plants, and something disastrous would certainly happen if they were so used. Referring to some experiments with horn-break switches, he stated that he had obtained arcs as long as 12 feet, and thought that the attendants would hardly care to operate gears which were subject to such powerful illumination. He looked forward to the time when return-current cut-outs would be generally fitted to all switchboards for generators running in parallel. It might be quite safe to short-circuit the modern alternator for a short time, but he would like to know if under such circumstances it would keep in phase.

Mr. Pearce. Mr. S. L. PEARCE considered the type of board to be employed depended to a great extent on the space available, and that for extra high-tension work there were only two permissible types, viz., "The Cellular" and "The Multi-frame," provided the latter has no high-tension parts within, say, 8 to 10 feet off the floor. All intermediate mechanism for operating the switches, such as the use of compressed air, etc., was, in his opinion, out of place; they all ought to be as directly operated as

possible. He preferred the use of oil-break fuses and switches on all high-tension circuits, as an effectual means of suppressing an arc and preventing any abnormal rise of pressure. He agreed that the question of providing fuses on the generators at all was a moot point. He was inclined to think it was better not to provide them, the short-circuiting current of modern three-phase generators being too low to damage the machines, he would therefore rely on the fuses at the substation ends of the feeders. Every one who had experienced the awkwardness of fuses blowing on the generators would appreciate these remarks. The crux of the whole question rested with the 'bus-bar arrangements, and referring to those shown in Fig. 18 J, adopted for the first instalment of the high-tension plant at Stuart Street, Manchester, he criticised the scheme as being unnecessarily complicated and as having one set of bars which would very probably not be used, and therefore entailing an unnecessary expenditure of capital. He did not consider either that it was at all necessary to put ammeters on all three-phases. The arrangement shown in Fig. 18 I, adopted for the second instalment of plant at Stuart Street, was far simpler, and as far as he could see would meet every possible contingency that might arise. He had little doubt that, in combined stations, both the lighting and traction 'bus-bars would permit of being coupled together, although it was perhaps wise to provide means of running them isolated if required. He was in favour of providing a speed indicator in conjunction with the synchronising equipment to facilitate paralleling operations. On the question of charging feeders, he preferred to do this by means of liquid rheostats rather than by any other method. Mr. Pearce.

Mr. W. H. Collis referred to the diagrams of connection indicated on Figures 17 and 18, and suggested that the methods shown introducing numerous interconnecting switches as on Figure J were likely to cause trouble and mistakes. He had had experience with switchboards at Liverpool, and was in favour of simplicity in connection. As regards fuses, they had much trouble with them on generator circuits, but now they had no fuses and experienced no trouble. Mr. Collis.

Mr. A. Still, commenting upon the types of boards, described that shown in Fig. 1 as being very bad, and that in Fig. 2 as hardly any better, for the high-tension metal work was very close to the metal frame, and the horn-type of switch much too close to the 'bus-bars, in view of the possibilities of the 12-feet arcs. The position chosen for the fuses was bad, but it was a type that might be considerably improved by skilful design. He had seen a board at St. Petersburg similar to that shown in Fig. 8, and his first impression of the simplicity of the arrangements on the platform was most favourable, but a visit below disclosed the bad feature of the scheme, the maze of rods, cranks, levers, etc., in fairly close proximity to the high-tension metal-work. He doubted the use of the mercury switch, and asked for more particulars of its action. He had heard that at the start some paraffin oil was placed over the mercury, but this was not renewed. Mr. Still.

Continuing his criticisms of the boards illustrated in the paper, he concurred with previous speakers in condemning the use of relays. He mentioned the difficulty sometimes experienced in the design of

Mr. Still. central stations in finding a way suitable for mounting the cellular switchgear described, and suggested that the switchgear should be independent of the wall for support. Turning to Fig. 12, he pointed out that an iron framework had been adopted by his firm in its design in order to minimise the difficulties of fixing the gear in place. It should be noted, however, that an arc to-frame was practically impossible. In the design of a switchboard simplicity was of the first importance, and he suggested the possibilities of a "double-fronted" board in which the front was divided into vertical compartments, whilst "the front at the back" would be separated by horizontal divisions. He thought that the use of switches at half-cock was dangerous, and instanced a case in which the operator might short-circuit two machines by coupling them to the synchronising bar at the same time, where if the plug system was used a machine could not be put in circuit improperly.

Mr. Edgcumbe. Mr. K. EDGCUMBE thought that measuring instruments had been overlooked somewhat by the author. Synchronisers should be capable of indicating (1) whether the periodicity were right, (2) whether the phase were the same, (3) whether the generator were running too fast or too slow. His firm had devised such an instrument, which consisted of a small rotary field motor, the stator being connected to the 'bus-bars, and the rotor to the generator. The direction of rotation of the rotor indicated whether the generator was running too fast or too slow, but if the periodicity and phase were exactly the same in each, then the rotor would take up a fixed position. In order that the indications might be seen at a distance, incandescent lamps were used, a red and green light being so arranged that either one or the other was obscured according to the direction of rotation of the rotor. This apparatus seemed to be a most ingenious solution of the problem, and to satisfy all requirements.

Mr. Cooper. Mr. A. G. COOPER said that the difficulties with the Ferranti switchboards began (owing to the narrow centres) when repairs were needed in the case of the older types, but this may have been improved in more recent designs. He had no difficulties with half-cock switches, and thought that Mr. Still had not stated the case properly. As regards synchronising of alternators, he thought that in most stations the arc lamp and fly-wheel method of phasing the alternators was in use.

Mr. Sheffield. Mr. T. W. SHEFFIELD gave his opinion as an engineer that the switches on switchboards should be "dry." They were more mechanical than switches worked in oil or other liquids.

Mr. Allcock. Mr. H. ALLCOCK asked the question why, at Deptford, the high-tension fuses were 4 or 5 feet long, whilst in Germany the average length was apparently 15 to 18 inches. He thought one or other must be entirely wrong. Such differences as these possibly accounted for the German manufacturers having secured large contracts at prices which English firms considered absurdly low.

Mr. Moss. Mr. J. Moss pointed to the need of some compensating device on the switchboard to maintain a constant potential automatically on the supply at all loads.

Mr. Guy.

Mr. A. F. Guy was interested in insulating materials used in switchboard construction, and suggested that allowance should be made for the different degrees of humidity of the atmosphere found in different countries when making comparisons as to insulation properties of various materials.

Mr. Wordingham.

Mr. C. H. Wordingham (*Chairman*) agreed that the switchboard was the nerve-centre of the system, and that it deserved the most careful attention when laying out the arrangements of a station. He should place safety of life as the first condition, and next efficiency. Much had been said upon the question of "backs" or "no-backs," and seeing that accessibility was a feature of the utmost importance, he thought those types which permitted the attendant to get all round to be the best. In large stations there was much to be said in favour of the separation of the generator switches from the circuit switches. The Board of Trade limit of 1,000 k.w. for a feeder introduced a large number of feeder panels, and therefore, rather than have one extensive switchboard and gallery, it was better to have a separate switchboard for the feeders apart from the dynamo board; the feeder-board in such case would be in the charge of another operator. He had heard of oil switches having fired, but he considered the evidence to be rather weak, and asked the author's opinion on this point. Unlike some of the speakers, he was grateful to the American workers for many things, but he admitted that in some instances there was some need for verification of the results claimed. He then alluded to the report of Mr. Rice's tests in America, in which some very striking experiments on high-pressure arcs were made. He remarked upon the difficulty there was in learning the exact truth about continental fuses and their efficiency under actual working conditions.

Dr Garrard.

Dr. C. C. Garrard (*communicated*): In connection with Mr. Clothier's paper, an account of some experiments I recently carried out may be of interest. A quarter of a mile of B.I.W. 7/20 lead-covered high-tension concentric cable wound on a drum was taken, and at one end the inner conductor was connected through a horn switch provided with a brass block, which made connection between the two horns, in series with a standard Ferranti oil-break switch, to one end of the high-tension side of a 5-k.w. transformer. The other end of the high-tension winding was connected to the outer conductor. The other end of the cable was provided with an adjustable spark-gap between inner and outer. The transformer was run off a copper-type alternator, which gave a nearly true sine curve. The pressure of the cable was 4,000 volts. The spark-gap at the far end was adjusted with a sufficient margin so that it did not spark across at the normal voltage. The charging current of this cable is, of course, very small, and a sufficiently low-reading ammeter was not at hand to measure it; the presence of a capacity current could be seen, in that an arc occurred when the horn switch was opened. On raising now the brass block which made connection between the two horns, this arc could be gradually increased in length from zero upwards, and it was found that at a particular length of arc the spark-gap at the end of the cable

Mr. Garrard. invariably sparked over. There was no question of the arc breaking and thus causing the spark-gap to go; always when the arc was a certain length the sparking at the gap took place. This is, of course, perfectly analogous to opening this high-tension alternating cable circuit by any form of open flare switch. If now the horns were short-circuited, and the circuit opened by means of the oil-break switch, no sparking at the gap occurred. The result that the arcing switch, under the conditions present, caused rises of P.D. in the cable was very conclusive. As to an explanation of this phenomenon, the following consideration may be of service. The condition of stability of an electric circuit is that its $\frac{\delta v}{\delta a}$ should be positive ($v =$ volts, $a =$ amperes). Now an arc in air between metals is an electric circuit whose $\frac{\delta v}{\delta a}$ is very liable to be negative—this being the reason that an arc lamp, for example, will only run with a balancing or steadying resistance in series with the arc. The same thing applies to the filament of a Nernst lamp when overrun. In drawing out an arc in the above cable circuit the condition is possible, at a particular length of the arc, in which the positive $\frac{\delta v}{\delta a}$ of the circuit is more than counterbalanced by the negative $\frac{\delta v}{\delta a}$ of the arc, the result being that the whole circuit is rendered unstable, and an abnormal rush of current occurs, which charges up the cable to a higher voltage, eventually breaking its insulation down at its weakest point, in this case the spark-gap. It would seem that an effect such as this is different to that produced by breaking an inductive circuit suddenly. As has been recently shown by Steinmetz, this is due to the energy of the induction suddenly collapsing on to the conductor, and charging it up electrostatically. In this connection the difference between the action of the oil-break switch on alternating and continuous current is very marked. Experience has shown that an oil-break switch, which will act perfectly well for breaking 400 to 500 k.w. at 6,000 volts alternating-current, will fail to act on 2,000 volts direct-current, at loads from 100 to 200 k.w. The oil-break switch is, in fact, with alternating-current, not a quick break in the true meaning of the word. An arc is drawn out for a certain very short interval of time underneath the oil. This arc can be looked upon as a mechanically weak conductor, upon which the oil presses and tends to rupture. Naturally the arc is mechanically weakest at the point where no current is passing; at this point the pressure of the oil overcomes the arc, and extinguishes it. The first time, therefore, the current crosses the zero line, the arc is put out. The current at this instant being zero, no rise in potential due to induction can occur. It is easy to see from this that the maximum energy required to be absorbed by the oil is that of half a complete cycle. Provided the amount of oil be kept above this minimum, no danger of firing of the oil is to be feared. As a matter of fact, all good oil-break switches have a large factor of safety in this respect, and are much to be preferred to open flare switches for high-tension alternating-current systems.

Mr. ALFRED DOXEY (*communicated*): Reverting to the relative advantages of the oil *versus* air break type of switch and fuse as applied to the working of high-tension alternating stations, an experience of some twelve years' working with machines ranging up to 1,000 k.w. each has led me to decide in favour of the oil-break for the following reason. We are all by this time pretty fully conversant with the property known as "Resonance" manifested by circuits consisting of some miles of concentric cable carrying inductive apparatus such as transformers, motors, etc. The effect of slowly opening a switch and thus drawing out an arc on such a circuit is to form an oscillating spark-gap which, at one particular length of arc, will develop violent surgings and a superposing of voltage on the circuit with the possibility of a puncture at the weakest point of insulation on the system. The particular point at which the property of resonance is brought into play will of course vary with each particular circuit, but in drawing an arc we slowly increase our spark-gap, and thus run right across the gamut, and therefore will most certainly be in tune at some point of the scale. The danger, therefore, lies in allowing the arc to remain at this critical point sufficiently long for the effect to become cumulative. On the other hand the danger becomes less as we increase the rapidity of the break, and I believe oil will do this more quickly than any other medium; and if this reasoning applies to a fuse, it applies equally to a switch, and having seen both switches and fuses of oil-break type act repeatedly, on large powers, and under pretty nearly every condition that can arise in practice, I feel every confidence in affirming that for alternating systems, possessing large capacity and self-induction, an oil-break is the best means of escape from the troubles I have mentioned. Mr. Doxey.

Mr. H. W. CLOTHIER (in reply): Of the many questions raised in this discussion, those relating to the action of liquid and flare switches respectively are of the greatest importance and interest at the moment, representing as they do a specific difference between British and German designs. The flare switch is undoubtedly easier and cheaper to make than the oil or water break switch, and as Mr. Sheffield has said, it is preferable to have a dry switchboard than one that has a number of pots filled with liquids. But the insulation of the cables, and, in fact, the insulation of the whole system, must have prior consideration. It is useless to equip a switchgear with switches that cannot be operated without running risks of injury to the rest of the equipment. The test referred to in my paper, and commented upon by Mr. Wordingham and Mr. Cowan, clearly proves that very high potentials can be obtained by allowing an arc to flare across the blades of a switch or between a pair of horns. I have recently had an opportunity of confirming these results, and therefore do not doubt their accuracy. Mr. Rice's tests in America were presumably made on circuits consisting of overhead lines, and, contrary to the suggestion made by Mr. Wordingham, I am of the opinion that the phenomenon is likely to be more effective in producing undesirable rises of potential on our transmission systems using underground cables which have a higher capacity or specific inductance than the overhead conductors. Mr. Clothier.

Mr. Clothier. Practical results show that the severe strains on the insulation of the system do not occur when oil-break switches are used. The oil-break switch prevents formation of an arc, and consequently is just the opposite to the flare switch. It has been explained that an oil-break switch always breaks the circuit at or near the value represented by the zero line on the simple harmonic curve: it does not break circuit at the maximum current strength, but allows it to force a way through the oil for the fraction of a second until the current is severed by the pressure of the oil at or near a minimum current strength. Whatever theories are advanced to explain the action of an oil-break switch, they can be of no greater service or more conclusive than the results of the tests which have been quoted. I have, therefore, no hesitation in saying that the flare switch as made on the Continent will become extinct for alternating-currents, and that the only surviving switches, for alternating-current systems, will be those which will not draw out and maintain an arc for any appreciable time.

The arguments for the switch also apply to the fuse; Mr. Allcock has asked why we should make more expensive fuses than is customary on the Continent; the answer is obvious, we endeavour to make fuses which, in blowing, will act without destroying the holder or breaking down the insulation of the switchboard or any part of the system. It is no easy task that our English engineers have set to the designers: it is quite possible to arrange a load with unity power-factor which any fuse can break without effort, but my experience is that with an inductive overload, a dead short, or at such times when emergencies occur and a fuse is called into requisition the design cannot be too substantial, and I am of the opinion that the fuses common to German practice would not bear the test to which our English designs (Ferranti oil-break, for example) have been subjected without causing arcs and injury to the parts in operation. In reply to Mr. Wordingham, there is no danger of the oil in a switch igniting, provided the right oil is used, and sufficient attention is given to keeping the parts clean and the surface of the oil free from carbon or dust, this being a question of design and up-keep.

Some members have applied my remarks to continuous-currents, but it will be remembered that my object was to discuss the requirements of alternating-currents only. The conditions of the two systems differ in so many respects that the same arguments do not apply to both. The instantaneous disruption of a continuous-current circuit would cause excessive potential rises proportionate to the self-induction of the circuit and to the suddenness of the break. The potential rise so occasioned under certain conditions of the load would probably be more severe than those attributed to resonance effects on the alternating-current system; but (in reply to Mr. Cooper) as regards the general construction, irrespective of details of the switchgear, the cellular type is equally applicable to continuous and to alternating-current systems. It is true that the connections of a continuous-current board are sometimes more complex than the present alternating-current gear, but I am convinced that this would not be the case had the same simplifying influence on both been brought to bear on the earlier designs. Even

with alternating-current gears there has been a great deal of misplaced ingenuity displayed; the diagrams which have been described alone give evidence of the complications which can be, and have been, introduced. A study of the essentials of the direct-current central station switchboard will prove that, given efficient attention and skill in design, the boards can be made to advantage on the cellular or Ferranti principle; thus eliminating the risks of fire, serious shocks and burns. I reason that it is quite possible for a person to be seriously injured by making contact with a normally low-tension conductor at a time when a high potential exists thereon, due to such causes as the too sudden break of a continuous-current circuit. Mr. Clothier.

Mr. Cooper has referred to the question of repairs on one panel when adjacent panels are alive; this is naturally a difficult and somewhat dangerous operation on any type of gear, but it is obviously more risky on those boards where live fittings are exposed near metal framework. It is in this particular that the Ferranti cellular gear offers such distinct advantages, because there is no metal framework used in the construction of high-tension parts, and each fitting is surrounded, as it were, by a box of insulating material.

Mr. Pearce's observations on the much-discussed subject of fuses or no fuses for alternators, and Mr. Collis's experiences at Liverpool with continuous-current generators, cannot fail to be of special value and interest at the moment. Fuses are indispensable on high-tension feeders, but on modern machines they can be avoided; for the large alternating-current generators in particular it is feasible to do without either fuses or any other automatic device. Mr. Pearce has also anticipated my views as to cable-charging devices for high-tension cables, and so furnished an answer to the question asked as to the best practice in this respect.

Mr. Still's opinion and Mr. Cowan's vivid description of the old types of flat boards and other designs of gears with backs and basements are so palpable and well recognised that they need no endorsement from me, but I would emphasise the duty due to humanity expressed by Mr. Wordingham's criticisms. The safety to life should be the first consideration and object in selection of any high-tension apparatus. The question raised as to insulation tests of insulating materials gives me the opportunity of proposing that a Technical Institution such as the Owens College should be of service to contractors and insulating material makers alike by making comparative tests on different marketable materials, and publishing the results.

The synchroniser which Mr. Edgcumbe has explained is no doubt a useful accessory to a station where the engine-speed is controlled by electric relay from the switchboard platform; but under ordinary conditions the engine-driver can tell by sound, if not by the marking of the flywheel, when he has overstepped the correct running speed. A single lamp used by the ordinary synchroniser will also indicate to the switchboard attendant (by the length of time between the glowing of the lamp) whether the speed is too fast or too slow, and as the machine is gradually run up to speed he soon acquires the practice of phasing by the usual single-lamp method. He learns when the machine has

Mr. Clothier. reached the correct speed, and he can see at once if the limit be exceeded by the lamp showing a gradually increasing length of period between the maxima of illumination.

Mr. Moss has suggested a difficult task in asking for an automatic control of the generating pressure, which is to compensate for the varying voltage drop on machine and the circuits between no load and full load. It is of course within the scope of the central station designer to carry out this ideal either by automatic control of the generator field regulators, or by the use of automatic variable ratio transformers or boosters on the outgoing feeders; but such devices, on account of the intricate parts and consequent uncertainty of the automatism, are likely to increase rather than to diminish the supervision required.

It is not easy accurately to apprise the value of switch-gear on account of the numerous methods of design in vogue and the diversity in construction and parts demanded, but at Mr. Wordingham's request I will add a table of costs representing as nearly as possible the values of central station switch-gears per kilowatt of generating plant installed, drawn out on the lines which have been discussed.

To conclude, I have to thank the members who have given interesting information by their able discussion, and feel that the proceedings can only result in generally improving the knowledge on the subject and so guard us against the use of inefficient designs.

Approximate Costs of Central Station Switch-gear per K.W. Generated, for Four Machines and Eight Feeders (excluding Cable-charging Gear and Station-recording Wattmeters.)

Size of Unit Employed. Single- or Three-phase.	With no Wattmeters or Power-factor Indicators.		With Indicating Wattmeters on Machines and Power-factor Indicators on Feeders.	
	'Bus-bars and Connections to Diagram A.	'Bus-bars and Connections to Diagram J.	'Bus-bars and Connections to Diagram A.	'Bus-bars and Connections to Diagram J.
	£	£	£	£
300 K.W. Single-phase ... ... 2,000 volts	0·55	1·1	0·8	1·25
600 K.W. Single-phase ... ... 2,000 volts	0·38	0·75	0·5	0·87
1,500 K.W. Three-phase ... ... 6,000 volts	0·35	0·65	0·45	0·75
3,000 K.W. Three-phase ... ... 6,000 volts	0·32	0·54	0·38	0·6

DUBLIN LOCAL SECTION.

THE LIGHTING AND DRIVING OF TEXTILE MILLS BY ELECTRICITY.

By Marshall Osborne, Associate Member.

(*Paper read at Meeting of Section May 29th*, 1902.)

The application of electricity to the majority of the manufacturing industries has long passed the experimental stage, and is an established commercial success. This applies equally well to the textile industry, although very little progress has been made in this direction in this country. While this may appear to indicate lack of enterprise on the part of our textile manufacturers, and, to some extent, this is undoubtedly the case, it should be borne in mind that in most countries where the greatest progress has been made in this connection, the conditions obtaining are more favourable to such progress than with us. There are in this country a large number of new mills being erected, which are arranged for a mechanical drive, although they are, for the most part, if not always, lighted electrically.

I propose to bring to your attention to-night some facts and figures, showing what has been done in other countries, both in lighting and driving textile mills by electricity.

LIGHTING.

Until the advent of the enclosed arc lamp, illumination by means of arc lamps was not satisfactory for many of the fine operations demanded in weaving and spinning, and incandescent lamps placed in close proximity to the work were generally used. The enclosed arc lamp, however, where it has been tried, has proved both satisfactory and efficient.

Its use has been most general in textile mills in the States, where many large plants have been installed, which are operating to the entire satisfaction of the mill-owners. The following information in reference to some of these installations, I trust, will prove of interest.

In the Lynchburg Cotton Mills, a new weaving mill, 125 ft. by 400 ft., of two stories, has its lower floor most effectively illuminated by 45 5-ampere double-reflector direct-current enclosed arc lamps. Although the columns that support the upper floor are in two rows, 8 ft. apart, and there is overhead shafting, connected to the looms by belts, yet the lighting is most satisfactory, each lamp illuminating 1,100 sq. ft. Work is carried on here equally well night and day, and the mill-owners are most enthusiastic as regards the advantages of the enclosed arc lamp. In the Berkshire Cotton Mills the weaving rooms, containing 2,404 cotton looms 5 ft. 6 in. high, belted from below, are lighted by 128 5-ampere enclosed arc lamps. A spinning room in the

same mill. 135 ft. by 500 ft., with machines 6 ft. high, is also effectively illuminated by 58 enclosed lamps. Numerous other examples follow, which show the extensive use made of enclosed arc lamps. Thus, the Olympia Mills use 375 alternating-current constant potential 6-ampere enclosed arc lamps, the Buffalo Cotton Mills use 250 of the same type, the Amory Mills use 260 direct constant current 6·6-ampere enclosed arc lamps, the Manchester Mills use 262 direct constant potential 5-ampere enclosed arc lamps.

Satisfactory results could not have been obtained in these mills with open arc lamps, and the cost of installing and operating incandescent lamps would have been much higher.

The principal advantage gained by the use of the enclosed arc lamp over the incandescent lamp is less capital outlay and lower cost of operation, the efficiency of the arc lamp being much higher. These points should receive careful consideration at the hands of those engaged in the lighting of mills or factories, although there are, undoubtedly, many operations in spinning the finer numbers of yarn and weaving fine damasks, where it is absolutely necessary for the light to be immediately over the work. In these cases incandescent lamps are invariably used in a modern mill, two or more, as may be required, being fixed over each loom or frame. In general, it may be said that arc lamps are most suited for work of a comparatively coarse nature, and in connection with which there is undoubtedly a very large field for them. As an indication of the superior efficiency of arc lighting, it may be noted that it has been found by experience that one enclosed arc lamp absorbing 480 watts, fixed at a suitable height, efficently illuminated an area of 1,100 sq. ft. where the materials dealt with were of a light colour. With materials of dark shades, however, this area is reduced to 600 sq. ft., but a number of incandescent lamps absorbing the same power would only illuminate half the above-mentioned areas to the same extent.

POWER.

The application of electric power to the operation of textile machinery has not, up to the present, made much progress in this country, and, although many striking advantages can be demonstrated in favour of the electric drive, it has not received that consideration on the part of our mill-owners which in their own interests would seem advisable. The most important of these advantages is undoubtedly the fact that, with the electric system, it is possible to concentrate the whole of the power required for operating an extensive mill, or collection of mills, which are scattered over a comparatively wide area, *into one central power plant.* By this system great economy in working costs, maintenance, and staff is obtained, as by the use of large steam engines and generators of an efficient type, the generating costs for power are reduced to a minimum; also, one staff only is required, instead of several independent staffs, as in the case of isolated steam plants. But even in the case of a single mill, very material advantages can be demonstrated in favour of the electric drive over the mechanical

system by means of belt or rope transmission, as a large amount of shafting and belting can be entirely dispensed with by the use of the former operated from one centrally-situated generating station by the application of motors at the points where power is required. The transmission can be so arranged as to give a very high efficiency, although the question of commercial economy, particularly in the first cost, limits the over-all efficiency between the engine shaft and frames or looms to 80 per cent. or 75 per cent., which is a decided advance on the average efficiency obtained with the mechanical system. The usual practice is to divide the shafting on the various floors into small sections, each section of which is operated by a separate motor. This renders the various sections and floors entirely independent of any other section or floor, which is not the case with the mechanical system, where each floor is driven separately by means of ropes or belts through one continuous shaft.

Further, the mechanical system necessitates the introduction of a large number of what may be properly called *power-wasting devices*, such as extra belts, cross belts, bevel wheels, and gears of all descriptions, in order that power may be applied exactly where required, in many cases in positions which necessitate drives at right angles to the main drive of the mill. This difficulty is entirely obviated in the electric system.

In many mechanically-driven mills the power is transmitted through various counter-shafts to the final point of application. In some cases as many as six line shafts are belted together, so that all the power required on the sixth shaft is transmitted through the other five. This necessarily results in an excessive waste of power, and increase of slip. The slip on the first belt is transmitted in an increasing ratio to all the others, until it finally reaches the sixth in a much more magnified degree than where it started at the first.

In order to demonstrate the actual results obtained in practice, the following examples indicating the progress in various countries of electricity applied to textile mill driving may be of general interest. It will be observed that almost every country engaged in textile manufactures is represented, whereas the largest textile manufacturing country is conspicuous by its absence.

The history of the development of the electric drive in the Olympia Mills, at Columbia, S.C., U.S.A., is of striking interest in this connection, and is briefly as follows :—

Some five or six years ago Messrs. W. B. Smith-Whaley & Co. erected two cotton mills at Columbia, each for about 12,000 spindles, one being driven by the usual steam engines belted to lines of shafting, and the other by electric motors, the generating plant for the latter being at a distance from the main building. According to Mr. Smith-Whaley, the cost of repairs in the electrically-driven mill is 50 per cent. less than in that of the mechanically-driven mill. It was found in the electrically-driven mill, owing to the speed being maintained at much higher average, that the production was greater in a given time than in the mechanically-operated mill, the actual increase being about 4 per cent. per machine, the quality of the product also being much improved.

When the large new Olympia Mills were to be built by the same people, it was decided to put down steam-driven electric generators, and drive the machines by motors. The main building measures 553 ft. by 151 ft., with a couple of towers for stairs, and tanks for the sprinklers. Attached to the middle of the rear wall is the machine shop. Close to it, and at the rear, is the engine-room and boiler-house, the former being 120 × 50 feet and the latter 140 × 40 feet. On the first floor are the weaving looms, and here the bales are unpacked. On the second floor, weaving, spooling, warping, and slashing are carried on. On the third floor is drawing, carding, and lapping. On the fourth floor are the spinning frames.

For this mill, of about 100,000 spindles, two sets of plans and estimates were prepared. One embodied electric transmission of power, the other mechanical. The estimates for the electrically-driven mill were found to be the cheaper, in that it was possible to—

(*a*) Reduce the cost of the building 10 per cent.
(*b*) Reduce the cost of shafting 61 per cent. (the largest size being 3 inches in diameter for some few lengths of 12 feet, the majority being 2⅜-in. diameter).
(*c*) Reduce the cost of belting and ropes 66 per cent.

The above saving more than compensated for the first cost of the electrical plant.

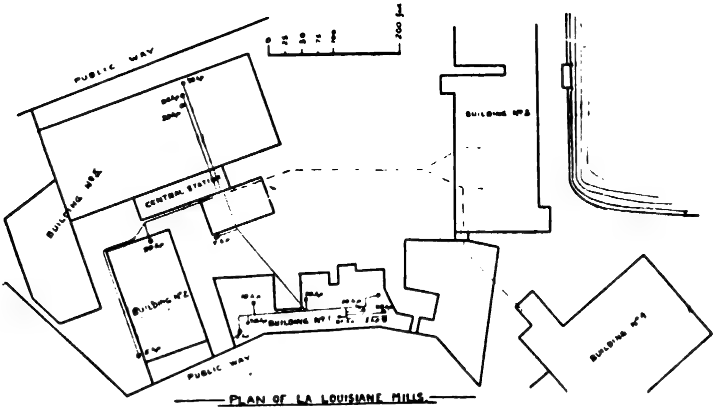
This illustration shows the plan and elevation of the power-house, which is designed for a maximum capacity at full load of 4,800 I.H.P., divided into three units of 1,600 I.H.P. each, at a speed of 123 revolutions per minute. The engines are of the compound type, having cylinders 20 in. and 48 in diameter, with a stroke of 42 in., and a steam pressure of 168 lbs. per square inch. These engines have a guaranteed steam consumption of 12·7 lbs. per I.H.P. per hour.

The generators are of the three-phase type, having 36 poles, of 1,300 k.w. capacity at 600 volts, and are directly connected to the above engines. The exciting current is obtained from a vertical marine-type direct-connected steam set of 75 k.w. capacity, which is also utilised for lighting purposes when the main engines are shut down. As a stand-by to the above, a direct-current generator of 75 k.w. capacity, driven by an induction motor at 600 revolutions per minute, is provided.

The motors driving the mill are :—22 induction motors, each of 150 H.P., 550 volts, and 588 revolutions per minute at full load. They are suspended from the roof, and generally are direct-connected in the centre of a 12 ft. shaft. Where the machines require very slow speed, counter-shafts are used, as in the case of looms and carding engines.

Six induction motors of 20 H.P. at 800 revolutions per minute operate four pumps and two hoists. Another motor of the same size is used in the opener room, and still another in the machine shop. For driving the cloth looms a 50 H.P. motor is installed.

The maximum requirements of the mill will be 3,600 H.P., leaving the balance available for other purposes, one of which is the driving of the Capital City Mills in the city of Columbia.



PLAN OF LA LOUISIANE MILLS.

GHENT.

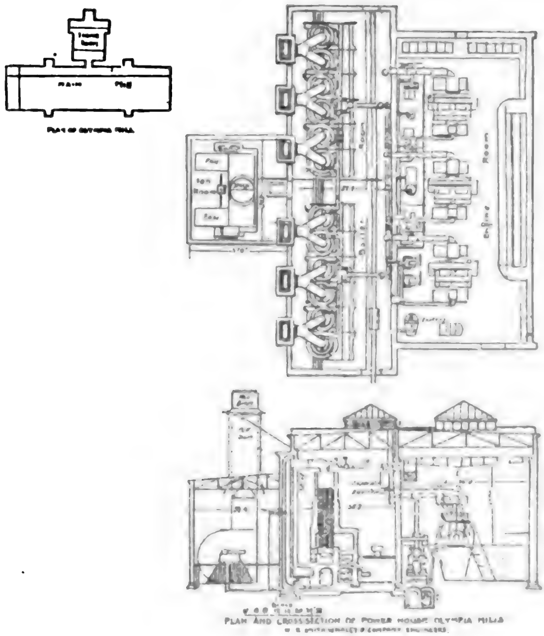


Illustration of Plans—"La Louisiane" Mills, Ghent, Belgium.

A point of mechanical interest is the low stack, 10 ft. in diameter, the draught being obtained from two 14 ft. fans driven by electric motors.

The above illustration is a good example of the use of motors suspended from the roof beams, in the Pelzer mill, which takes 3,000 H.P. from electric generating plant three miles distant.

In the Anderson Cotton Mills the motors and generators are ten miles apart. The point to be noted is that no belt or auxiliary shaft comes between the spinning frame and water-wheel.

Another good example of electricity driving a textile mill is at Montreal. Two mills—Hochelaga and St. Anne's—in the autumn of 1898 were driven by steam engines. The Hochelaga had three engines. Of two of these one was 28 years old, and the other in a quite good condition.

The St. Anne's mill was being extended, and instead of having new steam-engine power, the owners decided upon electric motors for driving the mills. They obtain power from the Montreal Royal Electric Company, involving transmission from Chambly, 17 miles distant. The question of using induction or synchronous motors was discussed, and the supply company strongly advocated the synchronous type of motor to ensure the company having a good power-factor. However, owing to the difficulty of starting these on load, and troubles with the clutch heating, so as to cause sparks, they were not used. Ultimately induction three-phase motors were installed, which overcame these difficulties. Four floors are driven by them. The weaving room has 300 H.P.; the carding room has 200 H.P.; the spinning room has 300 H.P.; and the mule spinning room has 150 H.P. The motors and the stairway are contained in a tower built for them, and a belt connects each motor with its mill shaft.

On the fourth floor there are four 60-k.w. transformers (one as a stand-by) for reducing the pressure from 2,200 volts to 500 volts or 100 volts as required, for about 100 H.P. in small motors.

To show the development of the electric drive in Belgium, the following is a brief description of the Spinning Company's Mills, La Louisiane, at Ghent.

From the plan it will be noted that the mill consists of several separate adjacent buildings. These are the outcome of gradual extensions. Four buildings made up the mill "La Louisiane," each of which was a complete unit with one or more steam engines. The engines were small and old, and the power-transmission losses were great. The many engines were costly, complicated, and inconvenient to maintain, and involved much supervision.

Owing to recent developments, the mill had to be extended, and a fifth building added. Thus a new steam engine of 1,500 H.P. was put down in a central power-house. It drives a three-phase generator at 400 volts, and has a frequency of 40 cycles per second. As soon as this was working, three engines were shut down in three buildings, and the machines operated by electric motors.

The power-house is arranged for two three-phase generators of 500 H.P. each, at 200 revolutions per minute.

Illustration of Cotton Mills, Spinning Room- Anderson, South Carolina, U.S.A.

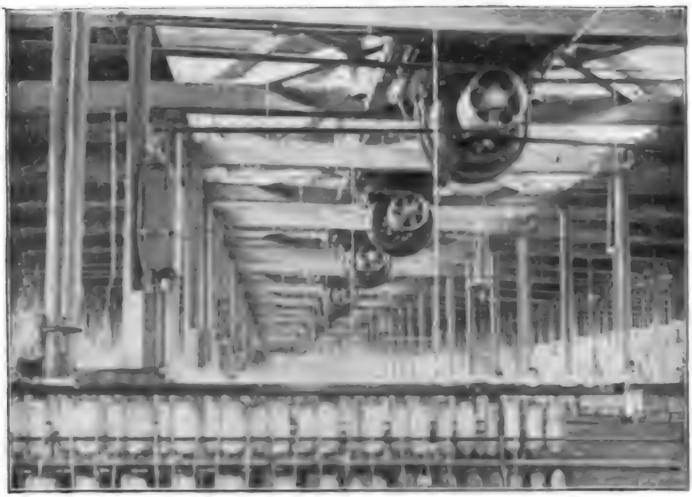


Illustration of Spinning Room—Pelzer Manufacturing Co., South Carolina, U.S.A.

All the motors are of the three-phase induction type. They are installed either on ordinary foundations, or suspended from the roof, as the conditions of each case demanded.

For lighting purposes, when the engine is shut down, a storage battery was installed. Two belt-driven direct-current generators are necessary for charging the battery, and are arranged so that they can be driven by direct-coupled induction motors at some future date.

A good example of a weaving factory completely driven by small motors is that of Messrs. Gavazzi, in Milan ; 336 looms are driven by ¼-H.P. three-phase motors. In such a case a very high power-factor is not to be expected. In their older factory at Desio a two-phase plant was installed six years ago for lighting, as they then feared bad regulation with three-phase generators.

Messrs. Gavazzi have found great uniformity in the motion of motor-driven looms, especially when gearing is used, compared to the older belt-driving, which allows during a turning or cycle of the loom a series of variations in the speed.

They use both incandescent and arc lamps for lighting, and consider that the three-phase system gives very satisfactory results.

The following indicates recent developments in Russia :—

The Prescheroff Factory, at Moscow, is a large mill, driven by motors and steam-driven generators.

The Central Station is about 1,000 ft. from the buildings requiring the power, and bare overhead conductors are used to carry three-phase current at 350 volts.

Two large generators driven by steam engines were installed for power, and one small set for lighting. The two larger machines were 1,574 k.w. and 970 k.w., with 1,800 and 1,200 H.P. engines respectively, and run at 75 revolutions per minute.

There are about 265 motors in the factory, varying in capacity from ½ H.P. to 200 H.P. Separate motors are used for each frame, in the spinning mill, which has a capacity of about 48,000 spindles, in the weaving rooms, with about 800 looms, and in the Chintz Factory, with about twenty-one machines printing from one to twelve colours.

The total power generated is about 2,000 k.w., with a power-factor of 0·8. The spinning mill takes 850 k.w., the weaving rooms 200 k.w., and the Chintz Factory 950 k.w.

The Voslauer Kammgarn Factory, at Voslau, in Austria, use electricity for both lighting and driving their mills.

Their lighting equipment is so arranged that each steam engine drives one or several generators, so that all rooms can receive both light and power from the same source. The cellars are lighted by a separate generator.

Light for the offices, after the regular working hours, is supplied by a storage battery, which also supplies light for different places in the factory. Light can also be had from this battery in case of a breakdown, and for repairing work executed during the night. Arc and incandescent lamps are used, which are distributed according to the nature of the work. For lighting purposes, direct current of 110 volts is used.

The electric transmission installation supplies the newly-erected and more distant parts of the manufactory with power, and also serve to drive elevators. The transmission is by belt, driven by 50 and 100 H.P. motors.

Three-phase current of 350-volt pressure is used for power work.

In May, 1900, before the Southern Cotton Spinners' Association Mr. S. Paine, of Boston, U.S.A., pointed out that only a year previously about 13,000 H.P. of electric motors were used in textile mills in the States, whilst at that date about 30,000 H.P. were in actual service, and on order. This very clearly indicates the enormous development of electric driving of textile mills in America. On the same occasion Mr. Paine pointed out that nine large textile mills had electric generators, driven by steam engines, to furnish electric power for motors, the horse-power of the mills varying from 600 to 5,100. At the present time one electrical manufacturing company alone has installed 40,000 H.P. of electric motors in textile mills in the U.S.A.

On the Continent, Russia and Italy have the largest and most numerous electrically-driven textile factories. Those in Italy total, roughly, about 9,000 H.P., and vary from 120 to 2,000 H.P. each. Some of the Italian mills are driven by a few large motors, and others by numerous small ones. The same is true of Russia, with, roughly, 8,000 H.P., varying from 300 H.P. to 2,600 H.P. per mill.

In France, the mills vary from 100 to 250 H.P.; in Germany, from 250 to 450 H.P.; and Austria, 500 H.P.

From the above it will be noted that the electrical operation of textile mills is most highly developed in America. Although on the Continent a few examples are found in nearly every country, the United Kingdom alone has not shown any great tendency to adopt this power for textile work, though signs are not wanting that our textile manufacturers are becoming alive to the needs of adopting electricity in driving their textile mills if they are to maintain their supremacy in the textile field.

Mr. Sheardown.

Mr. P. S. SHEARDOWN thought that in a properly designed factory where uniform illumination might be a necessity inverted arcs were preferable to enclosed arcs—for example, the cable works of the A.E.G. Co. in Berlin were thus illuminated. In a new factory there was no doubt that an electrical was far ahead of a mechanical drive, especially when uniform speed was essential. It was advantageous, if possible, to divide up the shafting and work so as to have only one size of motor in the works, or at any rate as few different sizes as possible, as this reduced the idle capital tied up in spare parts. He emphasised the much greater safety of the electrical drive, and suggested that special consideration should be given to this, in view of the stringency of the Employers' Liability Acts.

Mr. Ruddle.

Mr. M. RUDDLE said that Lancashire led the way in first lighting mills electrically in 1881. He thought the author placed the superiority of the enclosed arc rather high; much depended on the manner in which it was installed. A 16-c.p. lamp placed in the middle of four cloth looms gave a very good light, if the voltage was well attended to. He was not

altogether satisfied with the quality of enclosed arc lamps as regards intensity and colour of the light, and he had not found anything better for matching colours than the open arc. With very cheap gas, as obtained in Lancashire, it was sometimes questionable whether incandescent lighting could be made to pay. He pointed out that in Lancashire mills cotton ropes were used, not belts, and therefore the slip would not be so great as that stated by the author. Mr. Ruddle.

Mr. G. H. SAYER had tried many experiments in workshop lighting by inverted arcs, and had found the slope of roof and nature of ceiling very important. In malthouses he had found inverted arcs required cleaning two or three times a day, the malt screenings or dust being of a cloggy nature. Mr. Sayer.

Mr. I. SANDS said that the mill with which he was connected had 900 or 1,000 incandescent lamps. When first fitted it had been suggested to try arcs; two were erected, but had to be taken down, owing to the great concentration of light; these were replaced by about fourteen incandescent lamps, which were found to be much more suitable for the work. Ten years ago the company arranged to pay a contractor the same price for electric lighting as they had previously paid for gas; this was continued for a year, after which the contractor refused to go on. They now had a plant of their own. In a new mill it was much more satisfactory to have an electric drive, and he believed this accounted for America being ahead of us. He recently had to consider the question of taking out the main shafting and working motors on to subsidiary shafts, but found it too expensive to make the change. Mr. Sands

Mr. W. BREW said that he had fitted inverted arcs satisfactorily, and quoted tests of candle-power from open and enclosed arcs on both direct and alternating circuits; the mean spherical candle-power taken per watt was found to be as follows:— Mr Brew.

Open arc	...	1·16 direct current.
„	...	0·88 alternating current.
Enclosed arc	...	0·73 direct current.
„	...	0·55 alternating current.

The cost of carbons was, for open arc £3 per annum, and for enclosed arc £1 per annum. He thought that the red rays in underrun incandescent lamps put such lamps out of the question for matching colours. The paper was a testimony to the usefulness of three-phase motors; the power-factor mentioned, 0·8, was remarkable, and he believed it too high unless the motor was fully loaded. He asked if the author had made any measurements as to the length of time during which motors ran on full load in textile factories.

Mr. C. P. COOTE CUMMINS considered that the discussion which they had just heard very clearly indicated the great necessity there was for some standard of illumination such as the candle-foot, as suggested by Mr. A. P. Trotter. It was the business of electricians to satisfy the requirements of users of the electric light, and in order to do this they must make a study of the illuminating power of electric lamps under varying conditions; and in recommending a system of lighting, careful inquiry should be made as to the conditions under which the lamps Mr. Cummins.

Mr. Cummins. would be used, such as the state of the ceilings, floors, etc. If this were done more generally than it is at present, there would be far more value to the profession in the kind of discussion which they had just heard. As it was, they had one of the very men whom it was their business to satisfy expressing most unqualified disapproval of arc lamps as compared with incandescent lamps, and they were not really in a position to criticise his remarks, because, whilst he judged the lamps by their power of giving him what he wanted, electricians were only too apt to judge them by their candle-power.

With regard to the use of motors, he thought the argument that had been used against them, that they necessitated the employment of electrical expert workmen, was rather a humiliating one; there was not the slightest reason why the men employed at present to look after the machinery should not learn the very little there was to be learned in order that they might be able to look after the motor as well. With the educational facilities now offered, every man who wanted to learn could easily do so.

Mr. Osborne. Mr. M. OSBORNE, in reply, said that the experience in the United States was that inverted arcs were taken out and enclosed arcs substituted. He did not understand how one incandescent lamp of 16 c.p. could be sufficient to illuminate four looms; he had seen two such lamps to each loom, and thought that one to four looms must be a very poor light. It would be found that to give satisfactory light there would be required one or two 16 c.p. lamps at least per loom. It was certainly more difficult to make enclosed alternating arc lamps than the enclosed direct current, but it has been successfully accomplished, even for series lighting. As regards candle-power, it was very difficult to measure the candle-power of arc lamps. Enclosed arcs appeared not so bright close to the lamp, but the light was more diffused, uniform, and gave a more perfect final result, as one's eye had not to adjust itself to so great changes of maximum and minimum light. He wished there were one standard candle-power. The German standard is only 88 per cent. of the English.

As to power-factor of three-phase induction motors, this depended entirely on the type and design of each motor. With synchronous motors or rotary converters it might be practically anything up to unity, depending upon the magnetic flux. Over-excitation of such synchronous machines would help to counteract the effect of the induction motors and tend to keep the power-factor of a distribution system at unity.

GLASGOW LOCAL SECTION.

NOTES ON THE TESTING OF TRAMWAY MOTORS, AND AN INVESTIGATION INTO THEIR CHARACTERISTIC PROPERTIES.

By MICHAEL B. FIELD, Member.

(*Paper read at Meeting of Section, April* 8, 1902.)

SYNOPSIS OF PAPER.

Introductory remarks—Definition of "rating of tramway motors"—Testing-frame—Disadvantage of the Hopkinson-method—Connections employed—Description of test—Reduction to standard voltage and standard temperature—Example—Results tabulated, Tables, I.–VIII., plotted Figs. 3, 4—Leading features of motors under consideration—Connections for testing with less than 500 volts—Separation of losses, Note 1.—Starting current—Test for similarity of two motors used—Examples, Tables IX., X.—Effect of temperature on full-load efficiency—Prony brake—Determination of thermal characteristic—Correction for cooling—Flashing of motors—Reversal of direction of rotation—Volt-ampere characteristic, and determination of ampere—$\frac{R}{n}$ curve—Latter very nearly straight line—Deduction therefrom, Note 2—Determination of retarding torque, motors acting as electric brakes—Coefficients of adhesion in practice—Particular case as example—Change of velocity and distance traversed under varying accelerations, Note 3—Tractive effort diagrams—Allowance for angular acceleration of rotating parts—Best shape of efficiency curve—Diagram of controller positions for different routes—Average current over route—Current for minimum loss—Graphical methods of studying acceleration and retardation periods—Importance in connection with tube railways—Possible economies to be effected by studying manipulation of controller—Examples, Tables XI., XII.—Approximate formulæ—Comparison with graphical methods, Table XIII.

Very little attention is paid as a rule by British tramway engineers to the determination of the characteristic properties of the motors they purchase. The author has known cases where important contracts have been decided in favour of one firm or another because the particular motors offered have been rated higher than those of other competitors, when in all probability a full load test would have shown the accepted motor to be not one bit superior to those rejected. It is often considered sufficient by the tramway engineer to have one sample equipment of the new type proposed, mounted on a car and tried on the street. If the speed be about right, the motors show no signs of violent sparking, and do not become excessively hot towards the end of the day's working, the test will often be considered as satisfactory. Engineers sometimes specify that the equipment shall be capable of propelling a car of given weight over a given route with a stated number of stops for not more than a stated energy consumption expressed in k.w.-hours, the supply voltage being 500. Any one who

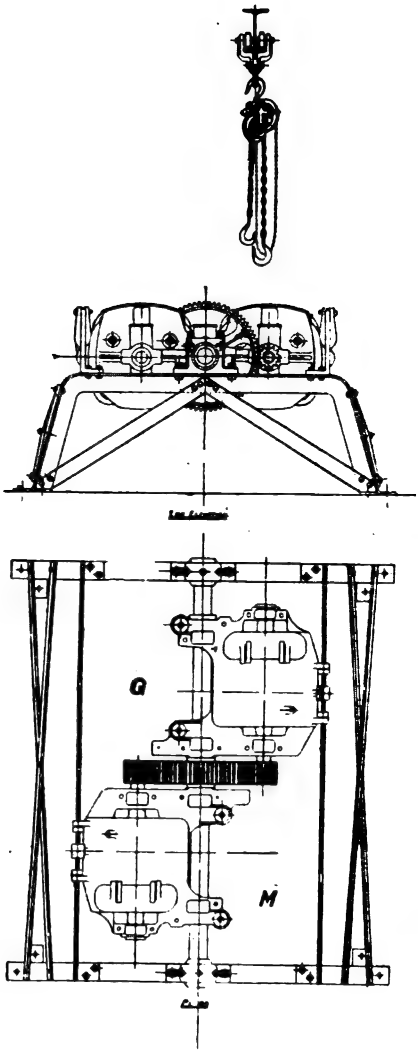


FIG. 1.—Testing Frame for Tramway Motors.

has made such tests will appreciate how entirely the results lie in the hands of the motorman.

The author is of the opinion, that the most satisfactory manner of arriving at the merits of the individual types is to supplement the above tests, taken on the road, by others carried out on the same motors mounted on a testing frame specially arranged for this purpose.

It is generally recognised now that it does not pay to put in motors which, although capable of doing all the work required of them without undue sparking, nevertheless heat more than 60° C. in so doing. There is consequently a liability with different manufacturers to rate their motors unequally. One, for instance, may call a motor a 40 H.P. motor because it is capable of delivering up to 40 H.P. intermittently, while another would call the same motor a 20 H.P. motor because it was not capable of giving out more power for any length of time without seriously heating the insulation. In order to avoid vagueness of this description American firms have adopted the following convention for rating tramway motors. The rating of a motor is that H.P. which it will give out continuously for one hour under working conditions with a rise of temperature measured with a thermometer nowhere exceeding 75° C., provided the atmospheric temperature is not more than 25° C.

When testing such motors stationary (*i.e.*, not mounted on a car), the ventilation and cooling facilities are manifestly less than would be the case on the road. To counterbalance this the lid above the commutator is usually left open, which has been found by experience to give a fairly correct compensation for the altered conditions.

The author has adopted this as a basis of comparison of a number

of different types of tramway motors in the past, and proposes to illustrate in this article how readily such motors may be quickly tested, and all their characteristic properties ascertained, in a practical workshop manner.

The motors under test are erected on the testing frame shown in Fig. 1, one of the gear wheels supplied with the equipment being used for the purpose. M works as motor, driving G, which works as generator, and is loaded on a water resistance. The current, after traversing the armature and field of M, passes also round the field of G. M and G being exactly similar, having the same ampere-turns on the field, and running at the same speed, it may be assumed that the iron and friction loss in each is the same. This is very important, as it enables us to arrive at the efficiency of M, and at the same time to separate out the losses far more accurately than can be done with the Hopkinson method.

For example, if we wished to determine the efficiency at 500 volts, 50 amperes, by means of the Hopkinson method, we could either

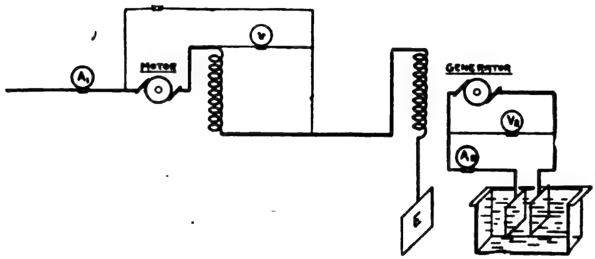


FIG. 2.

supply the losses mechanically by driving the combination by means of a belt, or electrically by including in the circuit an additional E.M.F. Suppose at 50 amperes the C^2R loss amounts to 9 per cent., and the gear and iron loss to 8 per cent., *i.e.*, efficiency of the motor = 83 per cent.; then in the first case it would be necessary to weaken the field of one motor by 18 per cent., and in the second case by 16 per cent. Under these circumstances it would be manifestly incorrect to take the square root of the combined efficiency as the efficiency of each motor.

Fig. 2 shows the diagram of connections for the method above described, and illustrated in Fig. 1.

If ${}_mR_a$ = resistance of motor-armature.
${}_gR_a$ = ,, generator-armature.
${}_mR_f$ = ,, motor-field.
Then A_1V_1 = input.
A_2V_2 = output.
$A_1V_1 - A_2V_2$ = total loss in motor and generator (but exclusive of generator field).

Subtracting from this the loss $A_1^2\,({}_mR_a + {}_mR_f) + A_2^2\,{}_gR_a$ or the known ohmic losses, we have as a remainder the total loss in motor and generator covered by hysteresis, eddies, friction, windage, etc. But for reasons already given, we may with very great accuracy apportion this loss half to the motor and half to the generator. The efficiency of the motor is then easily calculated. The voltmeter v allows of the resistance of the motor field being taken with each reading of input, output, etc.; the resistance of the armature is best taken at the beginning and end of each series of tests, when, if time readings be also taken, the actual resistance of the armatures for any particular reading may be easily found by interpolation. By taking simultaneous readings of supply voltage, current-input, speed, etc., etc., we can construct curves for k.w.-input, efficiency, hence H.P.-output. Then by aid of the speed curve we obtain tractive effort, and the volt-ampere characteristic for any desired speed.

With the exception of the last named all other results should be reduced to a standard voltage, say 500, and a standard temperature, say 20° C. This may be readily done, as the following example will show:—

Take $A_1 =$ 50 amperes.
$V_1 =$ 490 volts.
${}_mR_a =$ ·457 ohms determined by interpolation from initial and final readings, being approx. at 47° C.
(${}_mR_a =$ ·414 ohms at 20° C.).
${}_gR_a =$ ·446 ohms determined by interpolation from initial and final readings, being approx. at 40° C.
(${}_gR_a =$ ·414 ohms at 20° C.).
${}_mR_f =$ ·541 ohms determined by interpolation from initial and final readings, being approx. at 74° C.
(${}_mR_f =$ ·448 ohms at 20° C.).
$A_2 =$ 40 amperes.
$V_2 =$ 421 volts.
Speed = 422 r.p.m.
In this case the input = 24·5 k.w.
" " output = 16·84 k.w.

The actual total ohmic loss in armature and field of motor $= 50^2 \times (·457 + ·541) = 2·5$ k.w., and in generator armature $= 40^2 \times ·446 = ·714$ k.w., hence the total iron, friction, and windage loss = 4·45 k.w.

Now, of the 490 volts supplied to the motor, 50 volts are required to overcome ohmic resistance, leaving a back E.M.F. of 440 volts. If, however, the supply had been 50 amperes at 500 volts and the temperature 20° C., the back E.M.F. would have been 457 volts, *i.e.*, the speed would have been 439 r.p.m. instead of 422 r.p.m. We may then with great accuracy increase the iron and friction losses found above in this proportion, and dividing by two we obtain 2·31 k.w. as the motor iron and friction loss at 50 amps., 500 volts, 20° C. Using now the true values of the armature and field resistances at 20° C., we obtain as the corrected efficiency of the motor at 500 volts 50 amps. and 20° C., the result of 82 per cent.

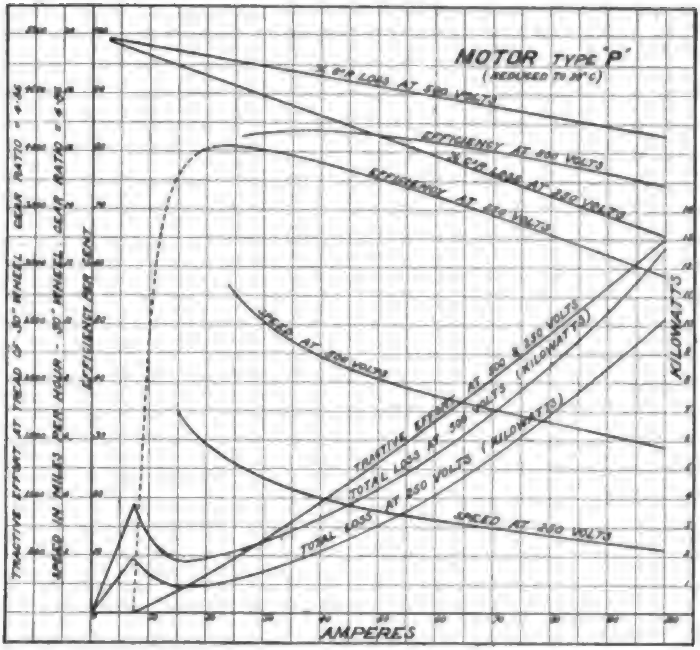

MOTOR TYPE "P"
(REDUCED TO 20°C)
% C²R LOSS AT 500 VOLTS
EFFICIENCY AT 500 VOLTS
% C²R LOSS AT 250 VOLTS
EFFICIENCY AT 250 VOLTS
SPEED AT 500 VOLTS
TRACTIVE EFFORT AT 500 & 250 VOLTS
TOTAL LOSS AT 500 VOLTS (KILOWATTS)
TOTAL LOSS AT 250 VOLTS (KILOWATTS)
SPEED AT 250 VOLTS
EFFICIENCY PER CENT
KILOWATTS
AMPERES

Fig. 3.

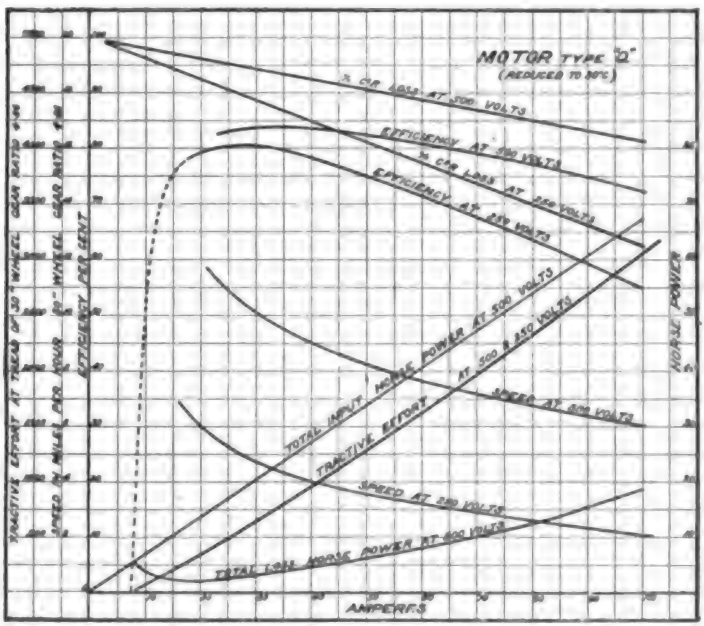

MOTOR TYPE "Q"
(REDUCED TO 20°C)
% C²R LOSS AT 500 VOLTS
EFFICIENCY AT 500 VOLTS
% C²R LOSS AT 250 VOLTS
EFFICIENCY AT 250 VOLTS
TOTAL INPUT HORSE POWER AT 500 VOLTS
TRACTIVE EFFORT AT 500 & 250 VOLTS
SPEED AT 500 VOLTS
SPEED AT 250 VOLTS
TOTAL LOSS HORSE POWER AT 500 VOLTS
EFFICIENCY PER CENT
HORSE POWER
AMPERES

Fig. 4.

Following this up, we should get with a 4·86 gear reduction (14 : 68) and 30-inch wheels, a speed of 8·1 miles per hour, an output of 27·5 H.P., and a tractive effort at the tread of the wheel of 1275 lbs., making no deduction for journal and rolling friction of the car truck. Tables I.–VIII. give the readings taken recently during tests on two different types (say P and Q) together with calculations thereon, while Figs. 3 and 4 show the various properties of the motors represented as curves, reduced to 500 volts and to 250 volts respectively, and to 20° C. In plotting the tractive effort curves no allowances are made for journal and rolling friction. In making calculations it is therefore necessary to deduct 15 to 20 lbs. per ton dead weight from the total tractive effort of the two motors, as given by these curves. This gives the effective tractive effort, producing acceleration or available for overcoming a grade as the case may be.

The leading features of the motors P and Q are as follows:—

	P.	Q.
Diameter of armature	346 mm.	345 mm.
Length of iron of armature	190 mm.	180 mm.
Number of slots	37	53
„ commutator bars	111	105
„ armature coils	37 × 3	105
Number of poles	4	4
Gear ratio	4·86	4·86
Weight of motor (without gear and gear case)	1856 lbs.	1924 lbs.
Weight of armature and pinion	476 lbs.	478 lbs.

Fig. 5 shows the connections for carrying out the 250 volt test, current being taken from the 500 volt supply. By adjusting the three plates in the water tub suitably 250 volts may be maintained at the terminals of the motor with any desired current strength.

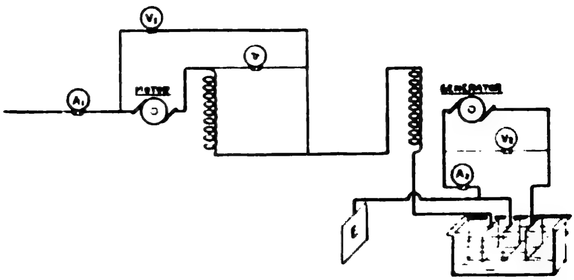


FIG. 5.

With the arrangement shown in Fig. 5 a whole series of tests may be carried out at different voltages. If the iron losses be separated for each reading and plotted, a set of curves can be obtained showing the

variation of iron and friction losses with speed for each field strength. Then adopting Kapp's method, viz., plotting loss divided by speed, or back torque with speed, it should be possible to separate out the Foucault current losses from the total iron and friction loss. (*See Note 1 at end of Paper.*)

For determining the starting current of a motor (this being the starting point of the efficiency curve) one motor is removed entirely from the frame, and sufficient resistance introduced into the circuit of the other to bring it just to the point of starting. It will be shown later that the determination of this starting current is of considerable importance.

It is to be noted that the method of testing already described depends entirely on the assumption that the motors M and G are sufficiently similar, that with equal field currents and the same speed the E.M.F. generated in each armature is the same. A very slight difference in the length of the air-gap of the two motors would make this an unwarrantable assumption; but the author has found that with motors manufactured by good firms the assumption is well founded. In any case it is easily tested. The supply voltage to motor M and the drop in volts in the motor itself are known, hence the back E.M.F. Similarly the terminal volts of G and lost volts in armature of G are known, hence the "generated volts" of G can be determined. Since in both machines the brushes are exactly in the neutral position, the back E.M.F. of M should be the same as the "generated" E.M.F. of G if the above assumption be correct.

Tables IX. and X., which have been worked out for the two types of motor "P" and "Q," show how nearly the E.M.F.'s of the two motors of similar type are in agreement with one another.

In this connection it will be well to point out that a difference of 5 per cent. in these E.M.F.'s will not produce an error in the total efficiency, calculated as already explained, of more than 0·2 per cent.

In specifying efficiencies it is important to specify the temperature at which the test is to be taken; at the end of the hour's heat run, for example, the resistance will often be 30 per cent. higher than at the beginning, which may mean a diminution in the efficiency of fully 3 per cent.

Fig. 6 shows an independent method that I have occasionally used for obtaining the torque curve. The cast-iron pulley of the Prony brake is hollow, and partly filled with water, which effectively keeps down the temperature of the brake blocks within reasonable limits. I have used such a brake up to 100 H.P. The length of the arm in this case is 5 feet 3 inches, this being so chosen that the lbs. pull × revolutions per minute ÷ 1000 = H.P. The diameter of the cast-iron pulley is 30 inches, so that it exactly corresponds to a car wheel, the force at the tread being that indicated in the spring balance, multiplied by 4·2 and corrected for the weight of the lever arm. It is sometimes convenient to arrange a balance weight to counter-balance the weight of the lever arm, so that no correction is needed for this.

Returning now to the purely electrical method, I have found that

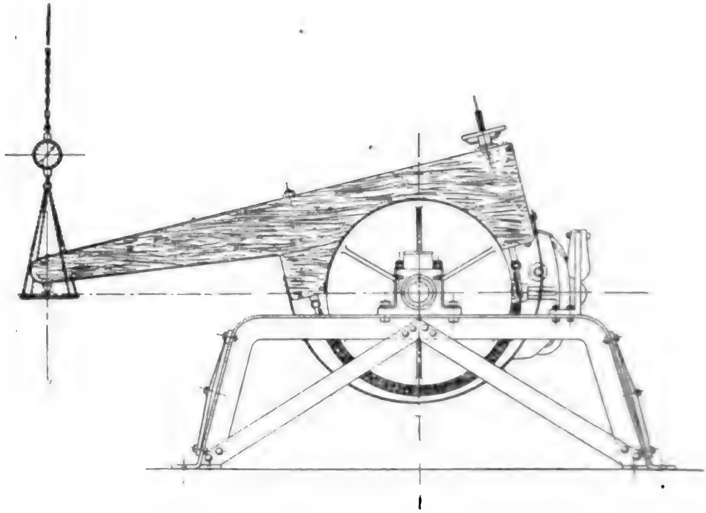


FIG. 6.

in carrying out the one-hour heat run it is most convenient to employ a special switchboard, Fig. 7, in which all the necessary connections are made once for all, the measuring instruments, after being standardised, being dropped into pockets and connected in circuit.

Before the commencement of the test (which we will suppose is being made to determine the rise of temperature after one hour at

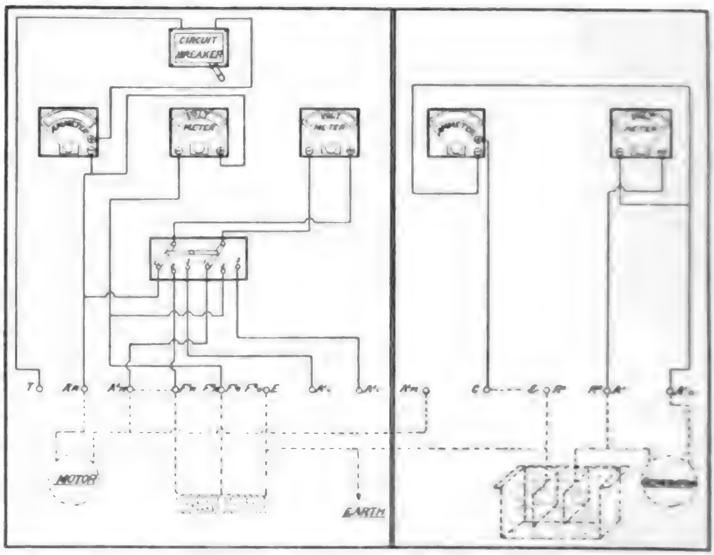


FIG. 7.

50 amps.) the connections between the terminals marked A^2_m and F^1_m and between C and ER^1 are removed, and those between C and A^2_m established. The current is now adjusted to 50 amps., and readings are taken with the three-way switch in positions 1 and 3. This gives the initial resistance of the two armatures, including carbon brushes and brush contacts (care having previously been taken that brushes are well bedded and not canted). A similar test is taken after the hour's run to determine the final resistance. If the rise of temperature as determined by rise of resistance be desired, it is best to have a copper brush that may be slid in in place of the carbon brush, as better contact will then be obtained.

To obtain the correct temperatures at the end of the heat run the author has found it best to employ bent thermometers, as shown in Fig. 8. Two holes are drilled through the motor case, through one of which a thermometer can, immediately after the test is finished, be

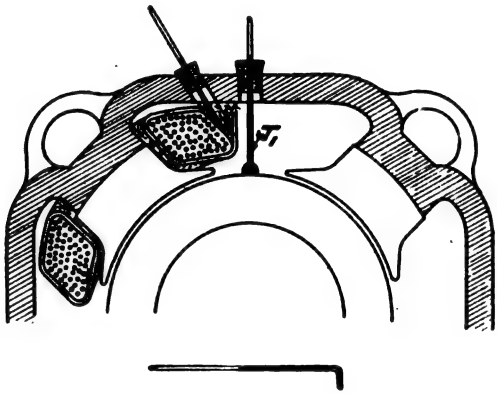


FIG. 8.

dropped down on to the surface of the armature. The bulb of the thermometer is protected by a cork hood to insulate it thermally. The second thermometer is packed into a pocket formed in the side of the field coil so that its bulb is lying up against the winding, as shown in Fig. 8.

With this arrangement the two thermometers are gradually rising towards their final temperature throughout the test, upon the conclusion of which no time need be lost in bringing T down on to the surface of the armature. A short interval of time must, however, elapse before the final temperature can be recorded, especially if a cold thermometer be laid upon the commutator to determine the rise of temperature of the latter.

If, however, time readings be taken from the finish of the test until the maximum temperatures are recorded, and then for an equal length of time further (during which the motors are cooling), a correction for the cooling-off during the first interval can readily be arrived at.

If the motors have to be opened up before the thermometers can

be applied to the surfaces it will be found that usually fifteen minutes elapse, and often a considerably longer period, before the final temperatures are recorded, during which time the motors will have cooled to a considerable extent.

In making this test care should be taken that there is no excessive pressure between brushes and commutator, also that there is no sparking which can be avoided—that is, which is not inherent in the motor, *e.g.*, such as might result from unfair vibration of the frame; for an abnormal commutator temperature will naturally heat the air inside the motor case to a greater extent, and cause both armature and field coils to show a higher final temperature than otherwise.[1]

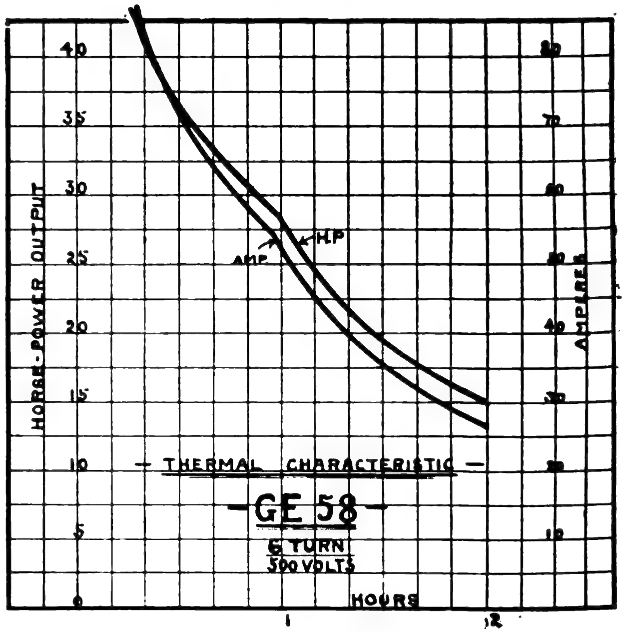


FIG. 9.

[1] The following figures are interesting as bearing on the subject. The same motor was tested twice at exactly the same load. In the first case the brushes were sparking badly and the friction was excessive. The increased rise of temperature at all parts could therefore only have been due to the great temperature-rise of the commutator.

TEST I. *One hour's run:—*

Final temperature of	Armature	68° C.	Rise 49° C.
" "	Field Coils	70° C.	" 51° C.
" "	Commutator	111° C.	" 92° C.
" "	Atmosphere	19° C.	

TEST II. *Same motor, same load, one hour's run:—*

Final temperature of	Armature	68° C.	Rise 43° C.
" "	Field Coils	67·5° C.	" 47·5° C.
" "	Commutator	63° C.	" 43° C.
" "	Atmosphere	20° C.	

By making a series of such tests at different current inputs, in each case allowing the test to continue till 75° C. rise is reached at some part of the motor, the thermal characteristic can be obtained. It often happens that at the upper part of the curve the temperature is governed by the armature and at the lower part by the field coil. As an example, Fig. 9 shows the thermal characteristic for the well-known, though somewhat old-fashioned, G.E. 58 motor.

Before removing the motors from the testing frame it will be found a good plan to try them for flashing by connecting them up to a rheostatic brake controller, running them at a high speed, and then applying the brake (*i.e.*, short circuiting the motors after reversing the field connections, under which circumstances they act as generators

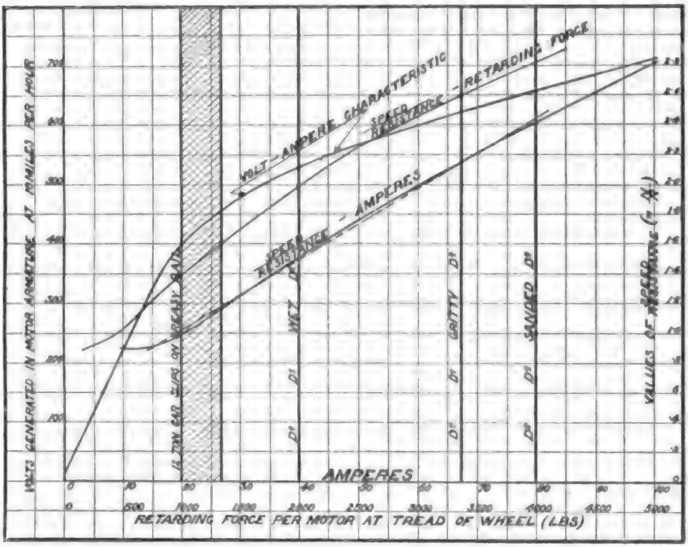


FIG. 10.

generating current in the closed circuit). A comparison of different motors from this point of view is of great importance.

In carrying out this test an interesting phenomenon will be noticed, viz., that if the brake be suddenly applied to the motors while running at a high speed they will quickly stop, and then run round in the reverse direction for a few revolutions. The reason of this most probably is that, owing to the large self-induction and small resistance of the short-circuited motors, the current generated has not died away by the time the motors have been brought to a standstill. This current still circulates then round the circuit as if supplied from an outside source, and the field magnets being reversed, the direction of rotation is reversed. There is, however, no further tendency to reversal of rotation, for the motors running in the reversed direction will not at any speed whatever generate current as generators unless their fields be again reversed.

Before leaving the subject of rheostatic braking the following considerations will be found of interest and importance :—

The E.M.F. generated in the armature of the motor working as a generator will be proportional to the speed n multiplied by some function of the current representing magnetic flux. We have in fact :—

$$V = CR = nf(C) \text{ or } \frac{n}{R} = \frac{C}{f(C)} = \phi(C).$$

Now, from the volt-ampere characteristic, which is easily constructed for any given speed from the figures tabulated, it is a simple matter to obtain the value of $\frac{n}{R}$ corresponding to any current strength.

Fig. 10 shows the volt-ampere characteristic for motor P, and the ampere — $\frac{n}{R}$ curve for two motors connected in parallel as in Fig. 11. *(See Note 2 at end.)*

It is to be noted that when the motors are being supplied with power from an external source the tractive effort at the tread of the wheel represents a smaller turning moment than that exercised on the armature (by the mutual action of field and armature current) multiplied by the gear ratio, by an amount depending on the iron and gear losses. When, however, the motors are short-circuited and acting as brakes the torque exerted by the rail on the car wheel must be greater than the retarding torque on the armature multiplied by the gear ratio, by approximately the same amount.

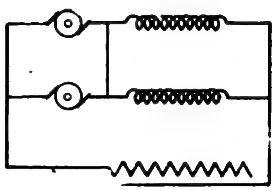


FIG. 11.

This means that a larger current can be put through the motors when supplying them with power, without skidding the wheels, than can circulate when the motors are themselves generating current to brake the car.

We may look at this matter in the following light :—

Referring to Fig. 11, we have $\eta_1 + \eta_2 + \eta_3 = 1$;
also $VC = $ Input into motor
Hence $VC\eta_1 = $ Output
$VC\eta_2 = $ Gear, friction, and iron loss
$VC\eta_3 = C^2R$ (R being resistance of motor).

If $n = $ actual speed
$\nu = $ theoretical speed, *i.e.*, if R were zero
$T = $ actual torque at tread of wheel, motor being supplied with a current C
$\tau = $ theoretical torque, *i.e.*, if gear, iron, etc., loss were zero.

Then the "speed efficiency" or $\frac{n}{\nu} = 1 - \eta_3$,

$$\text{and lost speed or } (\nu - n) = \frac{\eta_3}{1 - \eta_3} \cdot n$$

$$\text{also the "torque efficiency," or } \frac{T}{\tau} = \frac{\eta_1}{\eta_1 + \eta_2}$$

$$\text{and lost torque or } \tau - T = \frac{\eta_2}{\eta_1} . T$$

Hence—

$$\frac{\text{Retarding force at tread when generating current C}}{\text{Tractive effort at tread when receiving current C as motor}} = \frac{\eta_1 + 2\eta_2}{\eta_1}$$

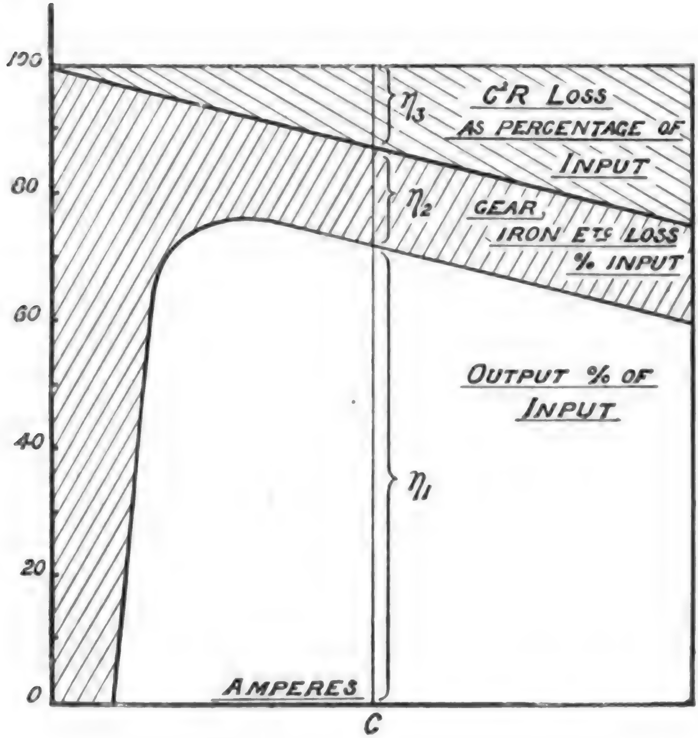


FIG. 12.

Taking this into consideration, the retarding force at the tread of the wheel has been shown also in Fig. 10 as a function of $\frac{n}{R}$. Now, we may take the adhesive force of a tramcar under different conditions as follows:—

Greasy rail	8–10 per cent. of dead weight.
Wet rail	15 „ „
Dry and clean	20 „ „
Gritty	25 „ „
Sanded	30 „ „

We will further take the resistance of each motor at ·96 ohm., and the external resistance on the different notches of the controller at 9·3, 7, 3·1. 1·1, and 0 ohms. respectively, *i.e.*,

Notch	1.	Total	resistance	in circuit	=	9·78	ohms.
„	2.	„	„	„	=	7·48	„
„	3.	„	„	„	=	3·58	„
„	4.	„	„	„	=	1·58	„
„	5.	„	„	„	=	·48	„

Referring to Fig. 10, we see that with a 12-ton four-wheel car, provided with one motor on each axle, travelling 19·5 miles per hour, with the controller on the first notch the retarding effort per pair of wheels will be 2,000 lbs.—*i.e.*, the wheels will be on the point of slipping on a wet rail. Now let the retarding effort fall to 1,040 lbs., then $\frac{n}{R} = 1{\cdot}43$—*i.e.*, $n = 14$ miles per hour. Suppose the controller is then moved on to the second notch, retarding force = 1,800 lbs. The speed falls to, say, 8·5 miles per hour before proceeding to the third notch, and so on, thus :—

Notch	1.	Retarding force falls from	2,000	to 1,040 ;	speed from	19·5	to	14·0
„	2.	„ „	1,800	„ 650 ;	„	14·0	..	8·5
„	3.	„ „	2,760	„ 500 ;	„	8·5	..	3·75
„	4.	„ „	2,800	„ 800 ;	„	3·75	..	2·0

Hand-brake applied.

On a good gritty rail there would probably be no slipping of the wheels, but on a wet rail there would probably be slipping for a moment when first coming on to the third and fourth notches. (*Note* 3.)

It will be at once recognised that the curves shown in Fig. 10 are most useful in helping us to estimate the heating effect on the motors and resistance, due to coasting down long grades with the rheostatic brake on, and are further applicable in all cases where this type of brake is employed, such as for cranes, lifts, hoists, mining machinery, etc., etc.

For studying the probable current required along a given route it is convenient to have the tractive effort necessary for propelling a given weight of car up different gradients, and for accelerating, drawn out on the same sheet. As an example, examine Fig. 13, drawn out for a 12-ton car as above described. The rolling and journal friction of the car-truck have been allowed for in the gradient line. They may, of course, be represented by a small up-grade. Thus this line does not pass through the origin.

In calculating the force necessary to produce a given acceleration it is necessary, not only to consider the lineal acceleration of the car as a whole, but also, the angular acceleration of all rotating parts.

We must, in fact, increase the actual dead weight of the car by a certain amount when calculating accelerations, to allow for the angular acceleration of motor armatures, wheels, etc.

If W = dead weight of car with all accessories in lbs.

r_1 = radius of gyration of armature shaft with armature, commutator, and pinion.

r_2 = radius of gyration of axle, with car wheels and gear wheel.

r = radius of car wheel.

w_1 = weight of armature shaft, armature, commutator and pinion in lbs.

w_2 = weight of axle, two car wheels, and one gear wheel in lbs.

ρ = gear ratio.

T = tractive effort—measured at tread of wheels—per axle, in lbs.

a = acceleration of car in miles per hour per second.

Then for a four-wheel car with two motors—

$$T = \cdot 0456 \left\{ \frac{W}{2} a + (w_1 r_1 \rho + w_2 r_2) \frac{a}{r} \right\}$$

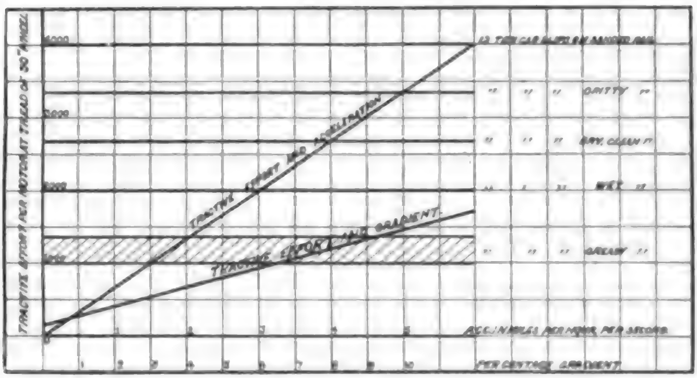


FIG. 13.

Thus for an ordinary case, such as has been assumed, from 9 to 10 per cent. should be added to the dead weight of the car, to allow for the angular acceleration of the rotating parts. This has been allowed for in Fig. 13.

Suppose we wish to find the current to accelerate a car up a grade of 5 per cent. three miles per hour per second, we see that for the acceleration alone 2,020 lbs. tractive effort is necessary; to this we add 800 lbs. to overcome the grade and friction, obtaining a total of 2,820 lbs.

On greasy rails the wheels would slip, but on sanded rails the car would mount with the desired acceleration with 90 amperes (motors in series).

Having obtained all the characteristic curves relative to the motor, the question at once arises, at what point is the efficiency of most importance to us, *i.e.* to say, what shape should the efficiency curve have in order to get the greatest commercial advantage?

This is a most difficult point to settle; it will naturally depend on

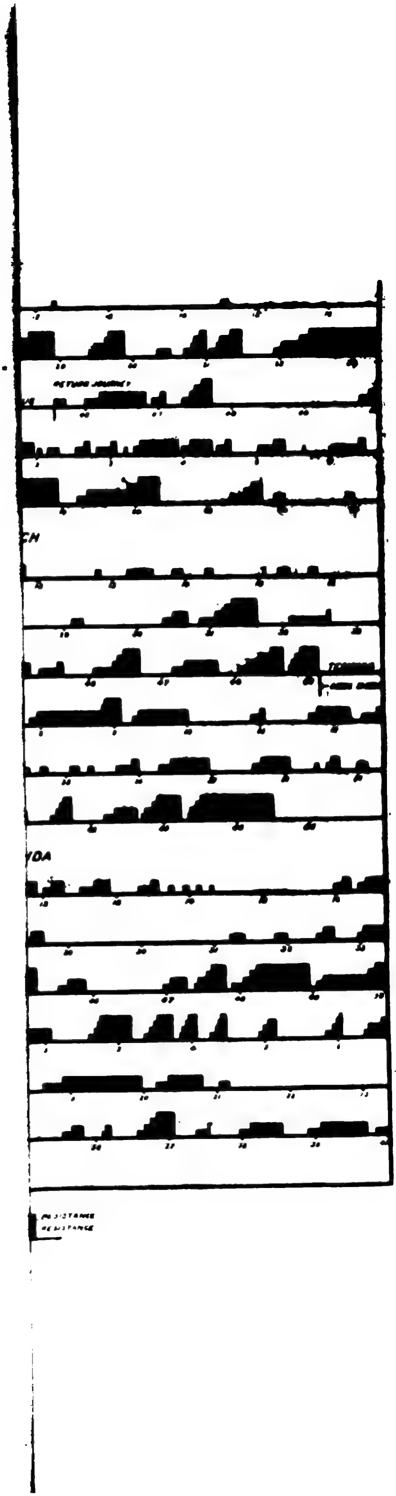
the nature of the route, hilly or otherwise, amount of traffic, average number of stops per hour, skill of motorman, maximum speed allowed by the Board of Trade, and a large number of other factors. I prefer to divide up the journey into five periods—(1) Current cut off; (2) running with resistance in circuit, motors in series; (3) full series; (4) resistance, with motors in parallel; (5) full parallel.

To show you roughly the proportion of these intervals I have constructed diagram Fig. 14, which shows three complete journeys at different times of the day, on different routes, and with different motormen. Time is represented horizontally, and the various intervals which were carefully observed under normal traffic conditions blocked in to form a square diagram. These journeys give the following analyses :—

Journey.	Time of day.	Total Time. Secs.	Total Time in Seconds for Periods. 1	2	3	4	5
Springburn to Pollokshaws and back ...	11 a.m.–12.30	5,070	2,756 54·2 %	625 12·4 %	758 15 %	253 5 %	678 13·4 %
London Road to Whiteinch and back ...	4 p.m.–4.55, and 3.30–4.20 p.m.	6,415	3,531 54·9 %	1,158 18 %	1,217 19·2 %	105 1·6 %	404 6·3 %
Mount Florida to Maryhill and back ...	11.15 a.m.–12.5, and 12.5–1 p.m.	6,738	3,600 53·3 %	1,124 16·7 %	1,507 22·5 %	142 2·1 %	363 5·4 %

Suppose after taking a large number of such tables on different routes, at different times of the day, and with different experienced motormen, we come to the conclusion that the current is cut off for 50 per cent. of the whole time, the series notches are in use during 35 per cent., and the parallel notches during 15 per cent. of the whole time.

Suppose, further, that from readings taken in the power-station we find the average current per car = 15 amperes, then the average current per car taken over the time that the current is actually on will be 30 amperes. We may assume, moreover, that the average current on the parallel notches is twice that on the series notches, which will result in an average current per motor of 23 amperes. In all probability the average current per motor during the time the motors are in full series and in full parallel will be less than this rather than more, since the momentary rushes of current during acceleration on the different controller notches are considerable. At present the average current per car for the Glasgow system is more nearly 12 amperes than 15 amperes, and it is, therefore, from considerations such as these that I am led to the belief that in Glasgow, at any rate, the 250-volt



efficiency curve just about the bend is of very great importance, and we should try to have as high an efficiency at this part as possible, even at the expense of a drooping efficiency curve at the higher current values.

This part of the curve is most difficult to obtain accurately, but a large number of points should be taken, so that the true shape of the bend can be studied. There is one point for each motor where the total motor loss will be a minimum. I have shown a "total loss" curve in Figs. 3 and 4; in Fig. 3 is shown the total loss in k.w. at 500 and 250 volts, and in Fig. 4 total loss in h.p. at 500 volts.

In Fig. 4 the line for h.p. input is also drawn to same scale, so that the difference between this and "total loss" curve represents b.h.p. at 500 volts.

It is interesting to compare the current corresponding to minimum loss with the average current per motor.

The writer is convinced that in many cases a considerable economy may be effected by giving due consideration to the manipulation of the controller.

Undoubtedly the most satisfactory way of studying the acceleration as also the retardation - periods is by means of a recording ammeter actually installed on a car.

My predecessor, Mr. A. E. Le Rossignol, worked with such an apparatus, it being arranged to record not only current, but speed, and the controller notch, simultaneously. This apparatus has been for a long time out of order, so that I am unable to place before you the results of any such tests. I hope, however, before long that we shall have time to set up this apparatus again in a practical shape. I will content myself, therefore, with merely giving here some graphical methods devised by myself for determining with considerable accuracy the current consumption and the curves of current, velocity, distance travelled, etc., during the acceleration and retardation periods. First, let us look at the retardation diagram, Fig. 15. Current per motor is plotted horizontally, and to the right-hand side a scale for values of $\frac{n}{R}$ is constructed vertically. Continuing in the same horizontal as the current scale a reversed speed scale is marked off, and a straight line curve connecting the values of $\frac{n}{R}$ and n is drawn for each value of R *i.e.*, for the five controller notches. The curve connecting retarding force at the tread of the wheels and $\frac{n}{R}$ is further constructed, the retarding force in lbs. being plotted horizontally. Beyond this a number of straight-line curves connecting retardation in miles per hour per second and lbs. retarding force per axle for a 12-ton car and a number of different grades have been drawn in. The friction of the car is here represented, for sake of simplicity, as 1 per cent. up grade.

This diagram then gives us very full information. We see, for example, we shall have 50 amperes per motor circulating, provided the car is travelling 17 miles per hour on first notch, or 13 nearly on the second, or 6¼ on third notch, or 2¾ on fourth notch, and so on, and for no other speeds. We see further that the retarding force for each of

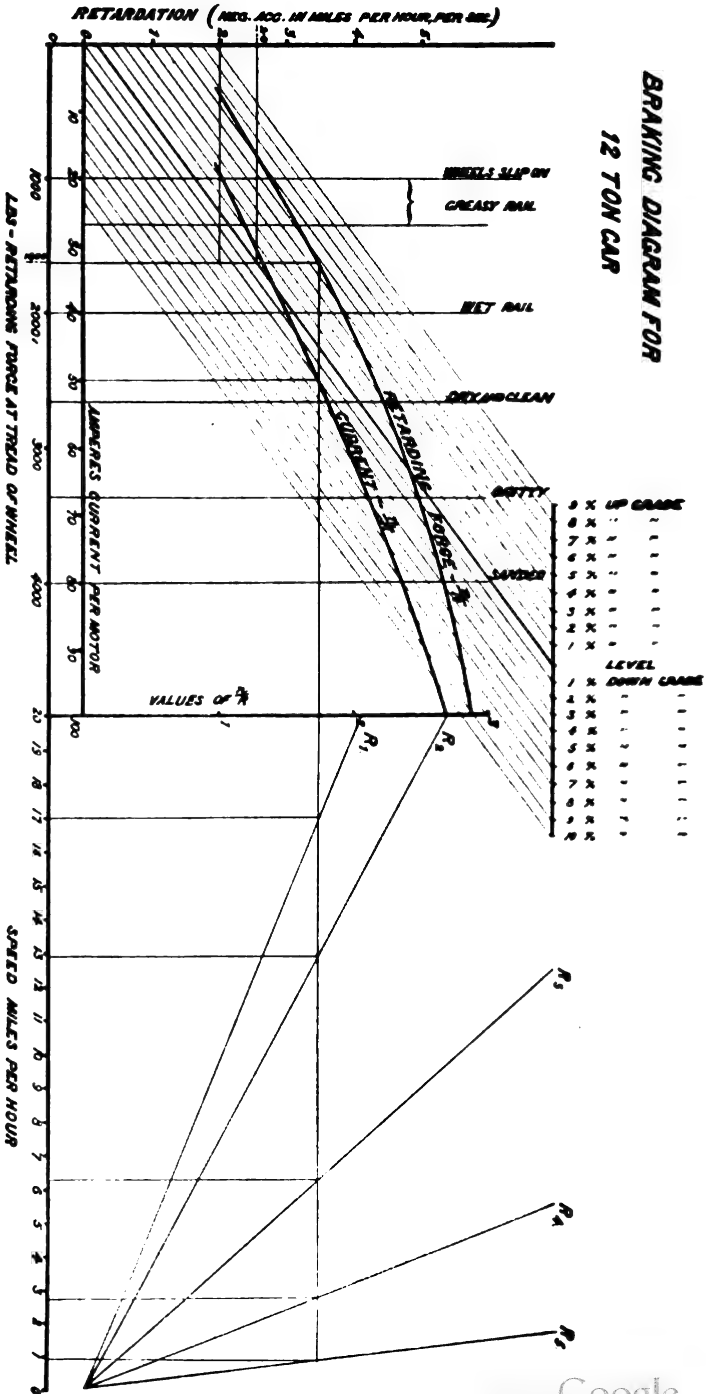

BRAKING DIAGRAM FOR
12 TON CAR
RETARDATION (NEG. ACC. IN MILES PER HOUR, PER SEC.)
LBS - RETARDING FORCE AT TREAD OF WHEEL
AMPERES CURRENT PER MOTOR
SPEED MILES PER HOUR
WHEELS SLIP ON
GREASY RAIL
WET RAIL
DRY AND CLEAN
GRITTY
SANDED
RETARDING FORCE
CURRENT
UP GRADE
LEVEL
DOWN GRADE

FIG. 15.

these speeds with the corresponding notch is 1,600 lbs.; that on greasy rails this would cause skidding of the wheels, but on a good wet rail ample adhesion would be obtained. Lastly, the same diagram gives s the retardation in miles per hour per second corresponding to the above retarding force on any up or down grade between 0 and 10 per cent.

We have then, with 50 amperes on the first notch, speed = 17 miles per hour, and a negative acceleration of 2·6 miles per hour per second on the level, or 2 miles per hour per second on a 3 per cent. down grade. Similarly for 35 amperes, if we follow the 35 ampere ordinate till we meet the current curve, then horizontally to the right till we cut

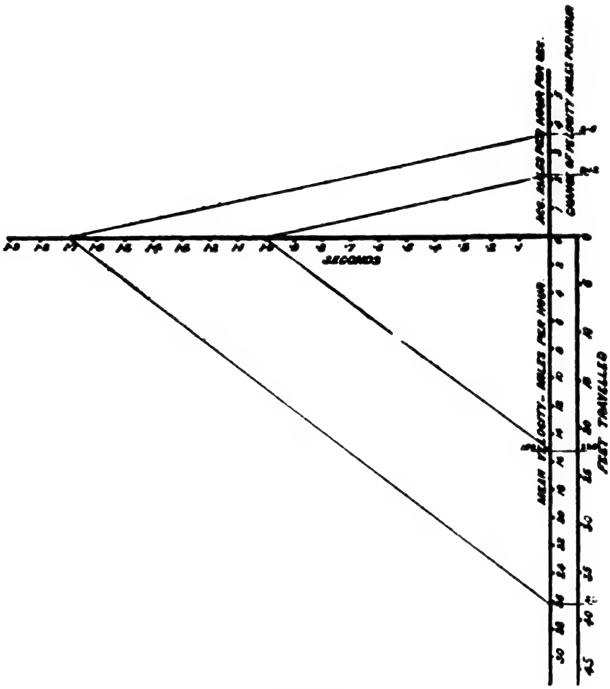


FIG. 16.

the $\frac{n}{R}$ line and drop vertically downwards on to the speed scale, we arrive at 13·4 miles per hour. Then travelling to the left after meeting the current curve till we cut the retarding force curve, then vertically again on to the "level grade" line, and again horizontally on to the vertical negative acceleration axis, we get for 35 amperes a value of 1·65. The mean retardation between 50 and 35 amperes is therefore 2·12 on the level, and the change of velocity 3·6 miles per hour. We may still continue graphically to find the time-interval required and space traversed. Refer to Fig. 16. Mark off on the vertical scale the mean negative acceleration 2·12 and the change of velocity, 3·6 miles per hour. Join the former point with the point denoting one second on the

time scale and draw a parallel through 3·6, when we find the time-interval 1·7 seconds. Now mark off on the lower vertical scale the mean velocity during the interval, *i.e.*, mean of 17 and 13·4, or 15·2 miles per hour. This, it will be seen, corresponds to 22·3 feet per second. Hence join this point with the point on the time scale denoting one second, and draw parallel through 1·7 seconds, giving the result of 38 feet as the distance traversed during the interval in question. We should then take, say, 28 amperes, and, proceeding as before, find the new time-interval, and other values corresponding to the range 35–28 amperes, and so on, constructing the various curves as we go.

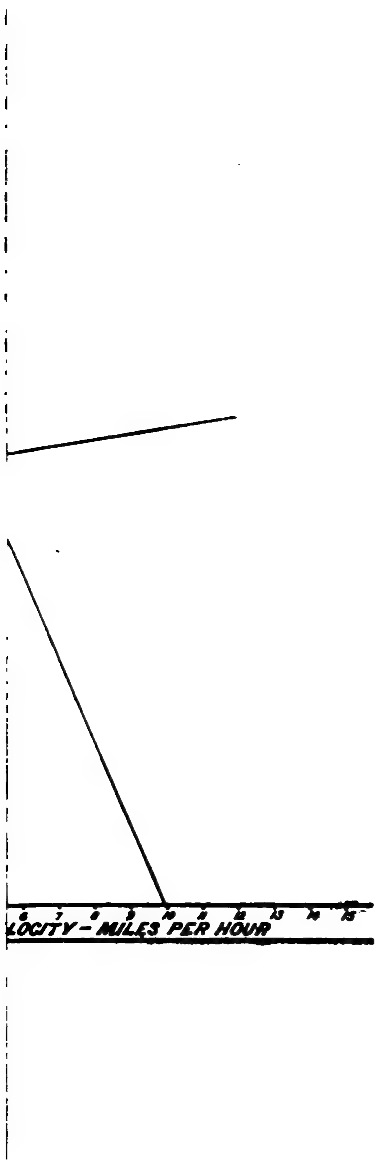
The writer personally prefers not to make use of Fig. 16 at all, but to plot current, time, and velocity as determined from Fig. 15 on a separate sheet and obtain the space-curve by integrating the velocity-time curve.

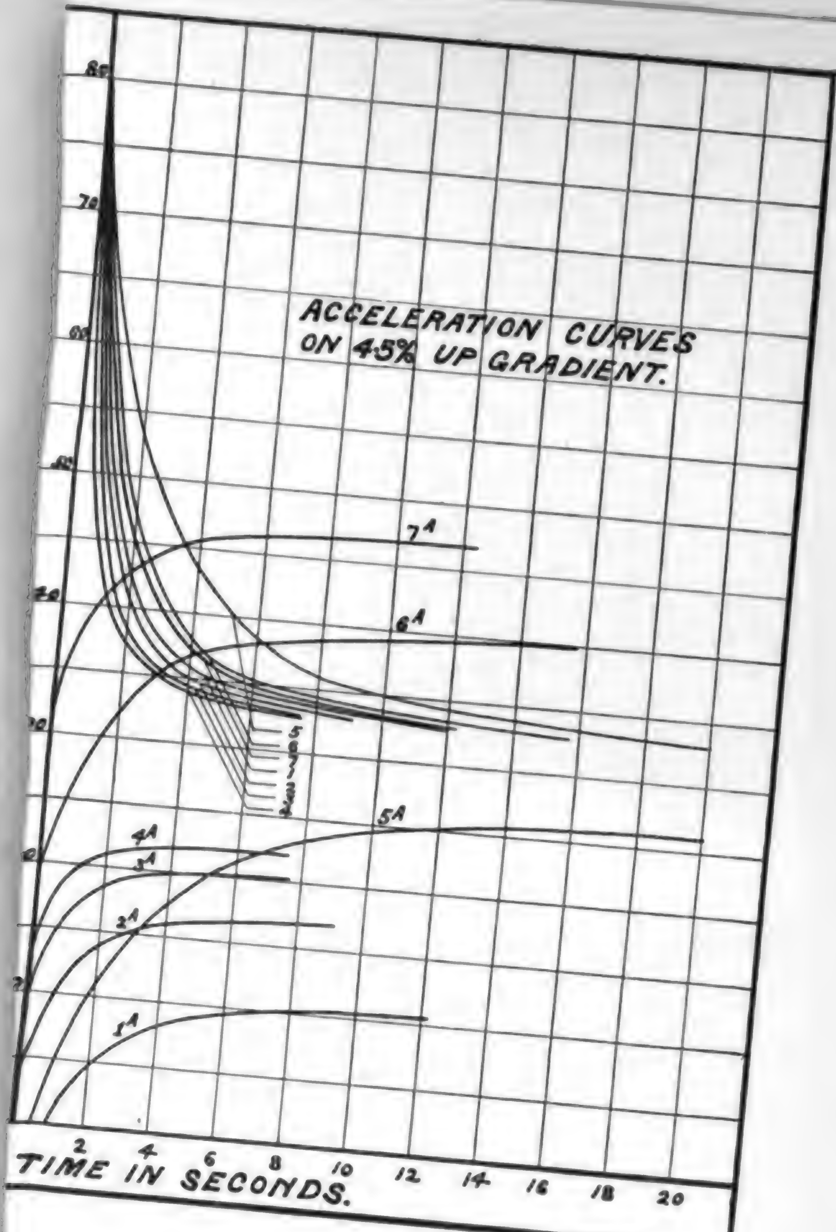
The acceleration diagram is somewhat different, see Fig. 17. Horizontally "total amperes" and acceleration scales are constructed, with a speed scale (not reversed) to the right as before, volts and tractive effort being plotted vertically. The ampere-volt-characteristic for 10 miles per hour is then drawn in (dotted). This is first doubled in the vertical and then in the horizontal direction, two new curves marked "total volt—ampere" and "total ampere—volt characteristic" being obtained. With 500 volts as the radiating point straight lines are drawn denoting the total CR drop in the circuit for the different values of the resistance on the various notches, the volt-drop being measured vertically downwards from the horizontal passing through 500 volts. Measuring from the zero line upwards we get back E.M.F., or 500 — C R. The upper characteristic gives the volts for two motors in series (with the same current C) if running at 10 miles per hour, hence by drawing parallels on to the speed axis we obtain the true speed at which the car is running.

An example will make this clear. Total current is 50 amperes, controller on R_2, *i.e.*, second series notch. Resistance = 5·02. Following the ordinate for 50 amperes vertically till it cuts the R_2 line, we find the length intercepted between the horizontal zero axis and R_2, or back E.M.F. = 249 volts, the C R drop being 251, viz., the portion intercepted between the R_2 line and the horizontal drawn through 500 volts. Following the same ordinate upwards to the dotted curve we see that 50 amperes give a back E.M.F. of 580 volts, hence two motors in series give 1,160 volts (*i.e.*, the point on the upper characteristic). 1,160 volts on the vertical axis, on the right-hand side of diagram, is therefore joined with 10 miles per hour on the speed scale, and a parallel drawn through 249 volts, giving an actual speed of 2·15 miles per hour. When working with the parallel notches we use the lower characteristic, since for any value of total current the amperes per motor are only half, and the voltage for any current on this curve is the same as for half the current measured on the dotted curve.

Accelerations, time intervals, and distance traversed are found exactly in same way as in the braking diagram. We have here, therefore, all information available for building up the whole acceleration diagram and computing the current consumption.

ERATION DIACRAM




ACCELERATION CURVES
ON 4.5% UP GRADIENT.
80
70
7A
6A
5A
4A
3A
2A
1A
2
4
6
8
10
12
14
16
18
20
TIME IN SECONDS.

Figs. 18 and 19 show the actual time-current, and time-speed curves, for the various controller notches, for motor P—

1. When braking on the level.
2. When braking on 4·5 per cent. down grade.
3. When accelerating on level.
4. When accelerating on 4·5 per cent. up grade.

They have all been calculated on the time-interval method above described, and on the assumption that no slipping occurs.

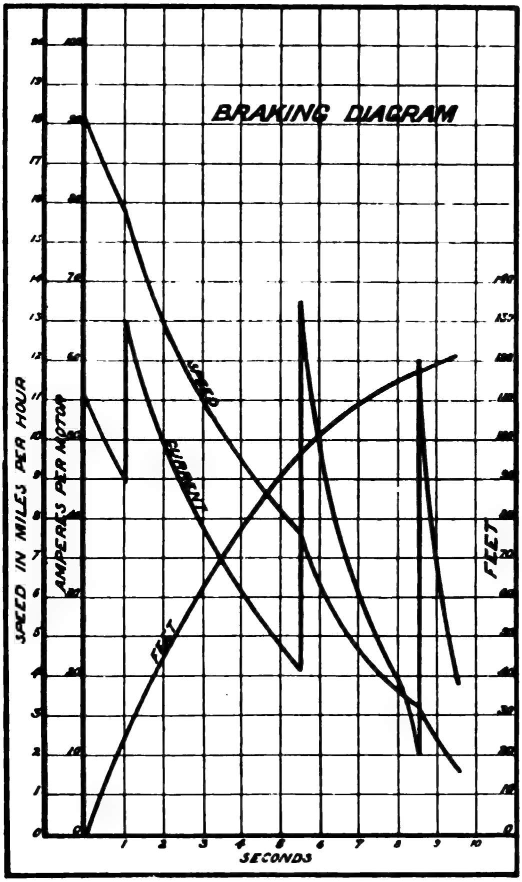


FIG. 20.

These curves enable us to formulate any programme whatever during the braking or accelerating periods on the given grades. We can, in fact, fit the various curves together in any way we like, and determine the current consumption, and time-speed curves for rapid accelerations or gradual accelerations. We have only to remember that the initial speed on any one notch must be the final speed on the

previous notch, and to postulate the length of time-interval to be allowed on each notch, in order to pick out the right portion of the current and speed-curves. Figs. 20 and 21 illustrate this, and need no further explanation.

These considerations are, of course, of the greatest importance when dealing with heavy, quick-service railways for city traffic with frequent stops, such as tube-railways, etc.

American engineers moreover (especially those who sell car-watt-meters) claim that, with ordinary tramways, variations amounting to from 20 to 30 per cent. in the total energy required by different motor-

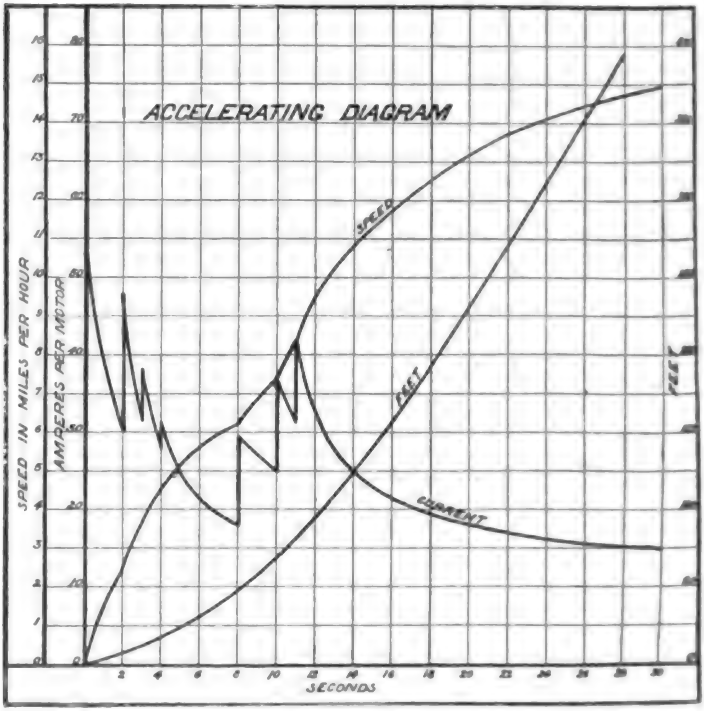


FIG. 21.

men, to drive the same car over the same route under the same conditions, are not uncommon. (*See Note* 4.)

Of course bad habits on the part of the motormen, such as applying the brakes before the current has been completely cut off, not cutting off the current soon enough before a recognised stopping-place, and thus failing to get any benefit from the kinetic energy in the car, or starting the car with the brakes partly on, etc., etc., may largely account for these discrepancies. Every motorman is supposed to have sufficient common sense to attend to these points, but over and above that, considerable waste may occur owing to too gradual acceleration. Table XI. gives one an idea of the extent of this. We see that on the

level the current consumption, as worked out from a combination diagram such as Fig. 21, may be at least 13 per cent. higher when accelerating gradually than when the acceleration is moderately rapid. On the up grade the difference indicated by Table XII. is 18 per cent. In each case the same distance is passed through, and practically the same final velocities are reached, so that the comparisons are as fair as can be.

It is needless to point out that a lengthened period of acceleration really implies running for a greater length of time on the resistance notches, which is manifestly inefficient.

In conclusion, I will merely add a few approximate formulæ for calculating the time-intervals corresponding to given current ranges, which are convenient if one desires to determine roughly the curves shown in Fig. 18 and 19, by calculation.

The formulæ are based on the assumption that $\frac{n}{R}$ can be represented by the expression $\alpha + \beta C$ (see *Note* 2). This will be found to be very nearly correct for up-to-date tramway motors over a considerable range. It cannot, of course, be pushed too far, but the formulæ here given must be used with discretion, the values of α and β being determined for each type of motor considered.

Let V = supply voltage.

$C_1\,C_2$ = higher and lower limits of current range (total current).

$E_1\,E_2$ = the back E.M.F.'s of motor with currents C_1 and C_2 at speed n.

r = total resistance in circuit.

T = mean effective tractive effort, or retarding effort producing acceleration, either positive or negative as case may be, corresponding to range $C_1 - C_2$.

ω = acceleration.

$n_1\,n_2$ = initial and final speeds corresponding to C_1 and C_2.

Then in case of applying the electric brakes—

$$n_1 = r\left(\alpha + \frac{\beta C_1}{2}\right)^{1}$$

$$n_2 = r\left(\alpha + \frac{\beta C_2}{2}\right)$$

$$n_1 - n_2 = \frac{r\beta(C_1 - C_2)}{2} \quad \ldots\ldots\ (1)$$

$$\text{time-interval} = \frac{r\beta(C_1 - C_2)}{2\,\omega} \quad \ldots\ldots\ (2)$$

In the case of acceleration—

$$\left.\begin{array}{l} \frac{n}{2E_1}(V - C_1 r) \\ \\ \frac{n}{2E_2}(V - C_2 r) \end{array}\right\} = \text{initial and final speeds, motors in series.}$$

[1] N.B.—In Fig. 10 current *per motor* is plotted with *total* resistance; we are here dealing with *total* current and *total* resistance.

$$\left.\begin{array}{l}\dfrac{n}{E_1}(V - C_1\, r) \\[2ex] \dfrac{n}{E_2}(V - C_2\, r)\end{array}\right\} = \quad ,, \quad ,, \quad ,, \quad ,, \quad ,, \quad ,, \text{ parallel.}$$

But $\dfrac{2\, n\, C_1}{E_1} = a + \beta\, C_1$ and $\dfrac{2\, n\, C_2}{E_2} = a + \beta\, C_2$, motors in series;

also $\dfrac{n\, C_1}{E_1} = a + \dfrac{\beta\, C_1}{2}$ and $\dfrac{n\, C_2}{E_2} = a + \dfrac{\beta\, C_2}{2}$,, ,, parallel.

Hence—

$$n_1 - n_2 = (C_1 - C_2)\left\{\frac{V\, a}{4\, C_1\, C_2} + \frac{\beta\, r}{4}\right\} \text{ motors in series} \quad . \quad . \quad (3)$$

$$n_1 - n_2 = (C_1 - C_2)\left\{\frac{V\, a}{C_1\, C_2} + \frac{\beta\, r}{2}\right\} \quad ,, \quad ,, \text{ parallel} \quad . \quad . \quad (4)$$

And the time-intervals in the two cases are expressed by—

$$\frac{C_1 - C_2}{\omega}\left\{\frac{V\, a}{4\, C_1\, C_2} + \frac{\beta\, r}{4}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$\frac{C_1 - C_2}{\omega}\left\{\frac{V\, a}{C_1\, C_2} + \frac{\beta\, r}{2}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In the case of the 12-ton car before referred to, using the values 0·554 and 0·0237 for a and β respectively, we can write:—
Braking—

$$n_1 - n_2 = 0{\cdot}0118\, r\,(C_1 - C_2);$$

$$\text{time-interval} = 8{\cdot}03 \quad r\frac{(C_1 - C_2)}{T}.$$

Accelerating—

$$(5) \text{ becomes } \frac{(C_1 - C_2)}{0{\cdot}00147\, T}\left\{\frac{69{\cdot}2}{C_1\, C_2} + 0{\cdot}0059\, r\right\}.$$

$$(6) \quad ,, \quad \frac{C_1 - C_2}{0{\cdot}00147\, T}\left\{\frac{277}{C_1\, C_2} + 0{\cdot}0118\, r\right\}.$$

Table XIII. gives a comparison of a few values, calculated from the above formulæ, with the correct values. I have now to acknowledge my indebtedness to Mr. G. Braid for the help he has given me in the preparation of the various tables and figures included in this paper. I further wish to mention that the results of actual tests have been appended here, not so much on account of the information they contain in themselves, as to exemplify the methods of testing and investigation with which the paper treats.

TABLE I.

TEST OF TRAMWAY MOTOR, TYPE P.

Table of Observed Readings at 500 volts.

No. of Reading.	Motor.		Generator.		Motor Field.		R.P.M.	Remarks.
	Volts.	Amps.	Volts.	Amps.	Volts.	Amps.		
1	523	23·8	491	15	12	23	643	
2	504	30	461	23	15·2	30·5	631	
3	500	34·5	451	26·5	17·5	35	504	
4	497	40·3	439	32	20·7	41	463	Res. of Motor Armature at 20° C. = ·414 ohm.
5	484	45·2	420	36	23·5	46·5	441	
6	488	50·3	416	40·7	25·5	50·5	422	
7	485	54·7	406	44·3	28	55	409	Res. of Gen. Armature at 20° C. = ·414 ohm.
8	475	60·5	387	50·3	31	61	380	
9	483	65·2	387	53·3	33	64	372	
10	484	70·2	380	58	36·7	69·5	361	Res. of Motor Fields at 20° C. = ·448 ohm.
11	475	76	360	62·8	40·5	75·5	336	
12	476	81·5	351	68	43·7	80	325	
13	461	85·2	329	71·3	48	88	303	
14	456	92	314	77	51	90·5	289	
15	468	98·5	314	82·7	54	95	283	
16	465	107·5	297	90	62	108	260	
					These readings taken simultaneously.			

TABLE II.

Table of Observed Readings at 250 volts.

No. of Reading.	Motor.		Generator.		Motor Field.		R.P.M.	Remarks.
	Volts.	Amps.	Volts.	Amps.	Volts.	Amps		
1	246	15·5	228	10	9	15·5	365	
2	255	19·5	231	14	11	19·5	325	
3	243	27·8	204	21	15·5	28	250	
4	249	40	193	32	22	40	211	
5	258	49·7	189	40·3	27·4	50	200	
6	253	59·2	169	48·3	32·2	59	170	
7	251	69·2	153	57·3	39·5	71	157	
8	251	87·5	121	74·3	51·8	89·5	129	
					These readings taken simultaneously.			

TABLE III.

TEST OF TRAMWAY MOTOR, TYPE Q.

Table of Observed Readings at 500 volts.

No. of Reading.	Motor. Volts.	Motor. Amps.	Generator. Volts.	Generator. Amps.	Motor Field. Volts.	Motor Field. Amps.	R.P.M.	Remarks.
1	503	21·5	463	15·4	14·6	21·5	630	
2	497	32	445	24·9	21	31	525	
3	506	35	443	28	23	34·5	517	
4	496	39·3	425	32·5	26·3	40	480	Res. of Motor Armature at 20° C. = ·423 ohm.
5	494	45·2	415	36·5	29·5	45	452	
6	484	50·7	396	42·5	33·8	51·5	425	
7	490	55·2	393	46·1	36·2	55·5	415	Res. of Gen. Armature at 20° C. = ·408 ohm.
8	490	60·1	385	51·9	40	60·5	398	
9	471	65·7	360	54	43·4	65·5	369	
10	475	71·6	350	61·7	48·6	72·8	351	Res. of Motor Fields at 20° C. = ·519 ohm.
11	476	74·8	347	63·1	50	75·1	347	
12	467	79·9	328	67·4	54	80·1	323	
13	471	86·9	320	74·2	59	87·5	311	
14	461	93·7	302	77·5	65	95	295	
15	455	101·4	281	84·9	68	99·8	275	

TABLE IV.

Table of Observed Readings at 250 volts.

No. of Reading.	Motor. Volts.	Motor. Amps.	Generator. Volts.	Generator. Amps.	Motor Field. Volts.	Motor Field. Amps.	R.P.M.	Remarks.
1	255	16	229	10·4	10·9	16	382	
2	250	19·5	219	14·4	12·9	19·5	320	
3	251	30·5	203	25·1	20	31	250	
4	255	42	187	35·5	27·5	42·5	210	
5	249	51·7	166	44·3	33·5	51·5	185	
6	254	64	152	55·5	42·6	65	170	
7	256	71·8	139	62·2	46·5	70	155	
8	247	81·3	110	70·5	55·2	81·5	129	
9	253	86·5	103	74·2	61·2	87	122	

TABLE V.

Table of Calculated Losses, Efficiency, etc., at 500 Volts. Motor, Type P.

No. of Reading.	Input. K.W.	Output. K.W.	Total Loss. K.W.	C^2R Loss in Motor at Test.	C^2R Loss in Gen. Armature.	Friction and Iron Losses in Motor at test.	Corrected Friction and Iron Losses for 500 volts and 20° C.	Efficiency at 500 volts and 20° C.	Speed in Miles per hour. 30-in. wheel. Gear ratio = 4·86.	Tractive effort at tread of 30-in. wheel in lbs. Gear ratio = 4·86.
1	12·45	7·37	5·08	·58	·10	2·20	2·11	78·2	11·33	413
2	15·12	10·60	4·52	·91	·25	1·68	1·68	83·6	11·61	543
3	17·25	11·95	5·30	1·21	·33	1·88	1·90	83·0	9·35	770
4	20·03	14·05	5·98	1·65	·48	1·88	1·92	83·5	8·67	975
5	21·87	15·12	6·75	2·08	·60	2·04	2·15	82·7	8·53	1101
6	24·55	16·93	7·62	2·57	·77	2·14	2·24	82·4	8·11	1284
7	26·53	17·99	8·54	3·04	·91	2·30	2·43	81·7	7·93	1416
8	28·74	19·46	9·28	3·72	1·17	2·20	2·38	81·7	7·55	1645
9	31·49	20·67	10·62	4·32	1·31	2·50	2·66	80·6	7·27	1817
10	33·97	22·04	11·93	5·01	1·56	2·68	2·85	79·8	7·04	2000
11	36·10	22·61	13·49	5·87	1·83	2·90	3·16	78·6	6·72	2234
12	38·80	23·86	14·94	6·75	2·14	3·03	3·31	77·8	6·52	2444
13	39·27	23·46	15·81	7·38	2·35	3·04	3·46	77·2	6·33	2611
14	41·96	24·17	17·79	8·60	2·74	3·23	3·75	75·9	6·16	2848
15	46·09	25·96	20·03	9·86	3·16	3·51	3·96	75·0	5·86	3168
16	50·00	26·73	23·27	10·73	3·75	4·40	5·03	72·1	5·46	3567

TABLE VI.

Table of Calculated Losses, Efficiency, etc., at 250 Volts. Motor, Type P.

No. of Reading.	Input. K.W.	Output. K.W.	Total Loss. K.W.	C^2R Loss in Motor at Test.	C^2R Loss in Gen. Armature.	Friction and Iron Losses in Motor at Test.	Corrected Friction and Iron Losses for 250 volts and 20° C.	Efficiency at 250 volts and 20° C.	Speed in Miles per hour. 30-in. wheel Gear ratio = 4·86.	Tractive effort at tread of 30-in. wheel in lbs. Gear ratio = 4·86.
1	3·81	2·28	1·53	·24	·05	·62	·71	76·3	6·90	215
2	4·07	3·23	1·74	·39	·09	·63	·60	80·2	5·91	333
3	6·75	4·28	2·47	·79	·20	·74	·79	79·0	4·83	572
4	9·96	6·17	3·79	1·63	·47	·85	·84	77·8	4·02	978
5	12·82	7·62	5·20	2·51	·75	·97	·89	75·7	3·67	1289
6	14·96	8·16	6·80	3·60	1·08	1·06	1·08	72·3	3·22	1671
7	17·37	8·76	8·61	4·71	1·52	1·19	1·35	68·3	3·02	1967
8	21·97	8·99	12·98	7·78	2·56	1·32	1·43	63·3	2·58	2720

TABLE VII.

Table of Calculated Losses, Efficiency, etc., at 500 Volts.
Motor, Type Q.

No. of Reading.	Input. K.W.	Output. K.W.	Total Loss. K.W.	C^2R Loss in Motor at Test.	C^2R Loss in Gen. Armature.	Friction and Iron Losses in Motor at Test.	Corrected Friction and Iron Losses for 500 volts and 20° C.	Efficiency at 500 volts and 25° C.	Speed in Miles per hour 30-in. wheel. Gear ratio = 4.86.	Tractive effort at tread of 30-in. wheel in lbs. Gear ratio 4.86.
1	10·81	7·13	3·68	·51	·12	1·53	1·54	82·0	11·64	381
2	15·90	11·08	4·82	1·24	·31	1·64	1·67	83·6	9·81	685
3	17·71	12·40	5·31	1·345	·39	1·79	1·79	83·2	9·73	752
4	19·49	13·81	5·68	1·70	·53	1·78	1·82	84·3	9·01	924
5	22·33	15·15	7·18	2·24	·67	2·14	2·20	81·8	8·54	1088
6	24·54	16·83	7·71	2·82	·90	2·00	2·11	82·1	8·15	1283
7	27·05	18·12	8·93	3·35	1·06	2·26	2·36	81·0	7·96	1412
8	29·45	19·98	9·47	3·97	1·35	2·03	2·12	82·6	7·64	1633
9	30·95	19·44	11·51	4·74	1·46	2·66	2·92	78·7	7·44	1747
10	34·01	21·59	12·42	5·63	1·90	2·45	2·67	79·0	7·04	2019
11	35·61	21·90	13·71	6·14	1·99	2·79	3·04	77·8	6·94	2107
12	37·31	22·11	15·20	7·01	2·27	2·96	3·32	76·6	6·65	2313
13	40·93	23·74	17·19	8·29	2·75	3·08	3·42	75·8	6·35	2607
14	43·19	23·40	19·79	9·64	3·00	3·58	4·12	73·5	6·24	2773
15	46·14	23·86	22·28	11·29	3·60	3·70	4·48	72·0	6·11	3003

TABLE VIII.

Table of Calculated Losses, Efficiency, etc., at 250 Volts.
Motor, Type Q.

No. of Reading.	Input. K.W.	Output. K.W.	Total Loss. K.W.	C^2R Loss in Motor at test. K.W.	C^2R Loss in Gen. Armature. K.W.	Friction and Iron Losses in Motor at test.	Corrected Friction and Iron Losses for 250 volts and 20° C.	Efficiency at 250 volts and 20° C.	Speed in Miles per hour. 30-in. wheel. Gear ratio = 4.86.	Tractive effort at tread of 30-in. wheel in lbs. Gear ratio = 4.86.
1	4·08	2·38	1·70	·28	·05	·69	·68	77·0	6·05	223
2	4·88	3·15	1·73	·42	·10	·61	·62	79·9	5·95	320
3	7·66	5·10	2·56	1·02	·32	·61	·62	80·3	4·65	662
4	10·71	6·64	4·07	1·94	·63	·75	·75	77·0	3·87	1050
5	12·87	7·35	5·52	2·93	·98	·81	·85	73·9	3·55	1353
6	16·26	8·44	7·82	4·50	1·54	·89	·92	70·1	3·22	1751
7	18·38	8·65	9·73	5·66	1·98	1·05	1·08	66·9	2·92	2068
8	20·08	7·76	12·32	7·26	2·49	1·29	1·41	62·4	2·58	2471
9	21·88	7·64	14·24	8·22	2·75	1·64	1·74	59·4	2·40	2601

TABLE IX. / TABLE X.

Motor Type P.		Motor Type Q.	
Back E.M.F. of A.	Generated E.M.F. of B.	Back E.M.F. of A.	Generated E.M.F. of B.
499	498	479	471
473	472	462	457
465	463	468	457
456	454	453	441
438	437	444	433
437	435	428	417
428	427	429	416
413	410	424	411
417	412	399	387
413	407	396	381
398	389	394	379
393	382	379	362
374	362	376	357
362	350	358	341
368	352	334	323

TABLE XI.

Rapid acceleration on level.

Notch.	Time. Seconds.	Initial Current.	Final Current.	Mean Current.	Current Consumption.	Initial Velocity.	Final Velocity.	Mean Velocity.	Distance Covered. Feet.
No. 1 Series	1·5	56	30	43	64·5	0	1·95	·98	2·15
No. 2 "	0·5	50	40	45	22·5	1·95	2·8	2·38	1·75
No. 3 "	0·5	56	40	48	24·0	2·8	3·6	3·20	2·35
No. 4 "	10·0	50	14·5	19·9	199·0	3·6	7·1	6·05	88·70
No. 1 Parallel	0·5	51	49·4	50·2	25·1	7·1	7·35	7·23	5·30
No. 2 "	0·5	71	64	67·4	33·7	7·35	7·85	7·60	5·57
No. 3 "	20·0	110	29	40	800·0	7·85	15·0	12·90	378·00
Totals	33·5				1168·8				483·82

Slow acceleration on level.

Notch.	Time. Seconds.	Initial Current.	Final Current.	Mean Current.	Current Consumption.	Initial Velocity.	Final Velocity.	Mean Velocity.	Distance Covered. Feet.
No. 1 Series	10	56	16	23·8	238·0	0	5·1	3·56	53·5
No. 2 "	5	19·5	16·5	18·0	90·0	5·1	5·8	5·5	40·3
No. 3 "	5	18	16	17·0	85·0	5·8	6·5	6·2	45·5
No. 4 "	5	16·7	15·5	16·1	80·5	6·5	6·8	6·7	49·0
No. 1 Parallel	10	53·2	34·4	43·8	438·0	6·8	10·4	8·2	120·1
No. 2 "	5	43	35·0	39·0	195·0	10·4	11·9	11·2	82·1
No. 3 "	5	41	34	37·6	188·0	11·9	13·6	12·8	93·5
Totals	45				1314·5				484

TABLE XII.

Rapid Acceleration on 4·5 per cent up gradient.

Notch.	Time Seconds.	Initial Current.	Final Current.	Mean Current.	Current Consumption.	Initial Velocity.	Final Velocity.	Mean Velocity	Distance, Covered. Feet.
No. 1 Series	2·0	56	40	48	96·0	0	1·3	·7	2·05
No. 2 "	1·0	65	45	55	55·0	1·3	2·5	1·9	2·70
No. 3 "	1·0	65	45	55	55·0	2·5	3·3	2·9	4·25
No. 4 "	5·0	55	33·5	40	200·0	3·3	4·4	4·1	20·45
No. 1 Parallel	2·3	75	71	73	299·0	4·4	4·8	4·6	16·20
No. 2 "	3·0	130	76	100	300·0	4·8	7·2	6·0	26·40
No. 3 "	16·0	130	67	72	1152·0	7·2	9·4	9·1	215·00
Totals	30·3				2157·0				287·14

Slow acceleration on 4·5 per cent up gradient.

Notch.	Time Seconds.	Initial Current.	Final Current.	Mean Current.	Current Consumption.	Initial Velocity.	Final Velocity.	Mean Velocity.	Distance Covered. Feet.
No. 1 Series	10	56	33	36	360·0	0	2·1	1·7	24·5
No. 2 "	5	52	34	43	215·0	2·1	3·3	2·7	19·8
No. 3 "	5	45	33	39	195·0	3·3	4·0	3·7	27·1
No. 4 "	5	40	33	36·5	182·5	4·0	4·4	4·2	30·8
No. 1 Parallel	10	75	68	71·4	714·0	4·4	5·2	4·8	70·4
No. 2 "	5	120	70	83·0	415·0	5·2	7·6	6·8	49·8
No. 3 "	5	110	80	95·0	475·0	7·6	9·2	8·8	64·5
Totals	45				2556·5				286·9

TABLE XIII.

Braking.

Current Range.	Resistance.	Speed Range Calculated from Formula	Speed Range True.	Time Interval Calculated from Formula.	Time Interval True.
160 to 140	8·92	2·11	1·78	·515	·434
140 to 120	"	"	1·96	·615	·571
120 to 100	"	"	2·14	·868	·881
100 to 80	"	"	2·32	1·152	1·268
80 to 60	"	"	2·14	1·674	1·697
60 to 40	"	"	2·32	1·973	2·165

The speed-range and time-interval corresponding to a given current range are directly proportional to the total resistance in circuit.

Accelerating.

Current Range.	Resistance.	Speed Range Calculated.	Speed Range True.	Time Interval Calculated.	Time Interval True.
Motors in Series.					
80 to 70	5·02	·421	·431	·136	·140
70 to 60	"	·462	·475	·182	·187
60 to 50	"	·528	·535	·264	·267
50 to 40	"	·643	·645	·435	·436
40 to 30	"	·874	·830	·891	·847
30 to 20	"	1·447	1·340	2·780	2·580
Motors in Parallel.					
160 to 140	1·58	·620	·68	·201	·220
140 to 120	"	·702	·74	·277	·290
120 to 100	"	·834	·83	·417	·415
100 to 80	"	1·064	1·06	·719	·716
80 to 60	"	1·528	1·62	1·560	1·652
60 to 40	"	2·680	2·24	5·160	4·305

NOTES.

Note 1.—For a given field strength, we may take the total iron and friction loss as $(H+f)\,n+Fn^2$, where H, f, and F represent the losses at the speed $n=1$ due to hysteresis, friction and windage, and Foucault currents respectively. Dividing this loss by n we should then obtain a linear relation between speed and $\frac{\text{loss}}{n}$, from which the value of $(H+f)$ and F can be easily determined. The writer has, however, not carried out this refinement in the case in question.

Note 2.—It is interesting to note that the $\frac{n}{R}$ and current curve is very nearly a straight line throughout the range shown. If we write

$$\frac{n}{R}=a+\beta C,$$

$$\text{and } \frac{n}{R}=\zeta\frac{C}{F}.$$

F being the total armature flux, or if we assume ζ includes a certain coefficient of magnetic leakage, we may say F = mean flux throughout the magnetic circuit. Now F is of the nature of an induction × an area or B × A. Let B stand for a mean effective induction, such that we can say total field magnet-ampere turns $\propto \frac{B}{\mu}$, μ being of the nature of a mean effective permeability for the circuit. A will be an area equal to $\frac{F}{B}$.

We have then $C \propto \frac{B}{\mu}$, which leads to the expression $\mu=\frac{\lambda-B}{\rho}$; a, β, ζ, λ ρ being unknown constants. This form of expression for μ for iron circuits

is well known; Dr. S. P. Thomson gives in his short article on dynamos in Munro & Jameson's Pocket-Book, $\mu = \frac{17{,}000 - B}{3{\cdot}5}$ as being approximately correct between 6,000 and 16,000 lines per sq. cm.

The linear relation of $\frac{n}{R}$ to C in motors of the type in question is of such interest that the author has shown in Fig. 10A the ampere — $\frac{n}{R}$ curve for motor Q, together with the mean calculated values of induction per sq. cm in different portions of the magnetic circuit, plotted with reference to current. It will be observed that inductions as high as 26,000 are indicated while the maximum induction in the teeth under the leading horns probably reaches over 30,000 lines per sq. cm. The values of α and β for motor P are ·554 and ·0237, and for motor Q ·56 and ·0244 respectively.

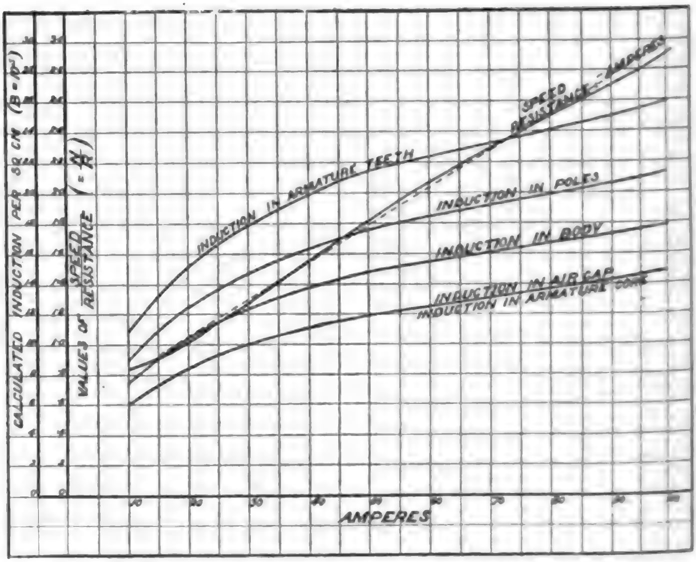


FIG. 10A.

Note 3.—If a sufficiently small time interval be taken during which one may assume that the tractive effort, or retarding effort, as the case may be, decreases uniformly, the total change of velocity during that time-interval is exactly equal to the mean acceleration multiplied by the time, but the distance traversed is *not* equal to one-half the mean acceleration multiplied by the square of the time, but to one-third of the maximum plus one-sixth of the minimum acceleration, multiplied by the square of the time.

In other words, if a represents acceleration,

a_0 a_1 represent the initial and final values of a taken over the time interval t_1,
k = rate of change of acceleration,
t = time in seconds,
t_1 = length of time interval,
v = velocity,
v_0 v_1 = initial and final velocities taken over time-interval t_1.
s = distance traversed,
S = total distance traversed in t_1,

We have the following relations :—

$$a = a_0 - k\,t$$
$$a_1 = a_0 - k\,t_1$$

Hence $v = v_0 + a_0 t - \dfrac{k\,t^2}{2}$

And $v_1 = v_0 + a_0 t_1 - \dfrac{k\,t_1^2}{2} = v_0 + \dfrac{a_0 + a_1}{2} t$

Or $v_1 - v_0 = \dfrac{a_0 + a_1}{2} t$

Further $s = v_0 t + \dfrac{a_0 t^2}{2} - \dfrac{k\,t^3}{6}$

$\therefore S = v_0 t_1 + \left(\dfrac{a_0}{3} + \dfrac{a_1}{6}\right) t_1^2$

If $a_0 - a_1$ be a sufficiently small quantity in comparison with a_1, or if $\dfrac{a_0 t}{2}$ is small compared with v_0 we may write $\dfrac{a_0 + a_1}{4}$ for $\dfrac{a_0}{3} + \dfrac{a_1}{6}$—*i.e.*, we may calculate the distance traversed from the mean acceleration.

It would be incorrect, however, to assume that the retarding force decreases uniformly throughout large ranges. The subsequent diagrams show that this is not the case.

Note 4.—Extract from *Electrical World and Engineer*, Dec. 16th, 1899 :—"Mr. Charles Hewitt, engineer of the Union Traction Company of Philadelphia, contributed a brief paper under the title of 'The Motorman as an Element of Street Railway Economy.' Tests were made by him by placing a wattmeter on a car without the knowledge of the motorman, and then having that car run on a number of routes by a number of different motormen. . . . The results showed that the number of passengers carried had an almost inappreciable effect on the watt-hours per car-mile, and that the variations in the amount of energy consumed depended almost entirely on the motorman. The watt-hours per car-mile varied very greatly for different motormen, but were nearly constant for the same motorman. They indicated that the usual test of a motor made in this way is really a test of the motorman. Omitting extremes, the saving of all motormen who were as good as the best, amounted to 43 per cent. The results showed what an important factor the motorman really is in the amount of power consumed by the cars, and how important it is to instruct the motormen properly in the most economical use of the controller."

Shortly after the inauguration of electric traction on the Springburn route in Glasgow, wattmeter readings were taken with different drivers, and variations from 860 to 1,080 watt-hours per car-mile were observed under conditions as nearly equal as possible.

In February, 1898, car-wattmeters were installed on all the cars of the Nashville Street Railway Company in America with the result that a reduction of 39 per cent. of the power consumed was effected within the first three months. This system possesses such physical features as give the greatest scope for the skill of a motorman to come into play. In level towns such reductions cannot of course be expected.

Mr. H. A. Mavor said that they as a Section were to be congratulated upon having the results of Mr. Field's work in Glasgow put before them in this way. At the same time he would have liked the paper much better if it had been somewhat less academical and more practical, from the motor builders' point of view, and if it had given fewer theoretical deductions and more information about how the results which the author had accomplished had been arrived at. As a manufacturer the Mr. Mavor.

Mr. Mavor. speaker would have found such information of the greatest interest, and as a citizen he thought that he was entitled to it. There were certain facts which could only be obtained from experience; many such facts must have been obtained by Mr. Field in the execution of his work in the Tramways Department; and as the City of Glasgow had paid for the plant upon which such experience had been gained, to the tune of many thousands of pounds, he thought they were entitled to ask that that experience should be at the service of their industrial community. For instance, one particular point to which Mr. Field had drawn attention was the necessity, in considering the acceleration of motor-driven gear, to take into account the acceleration of the motor-core. The weight of the armature is a necessary item of knowledge in making the calculation of acceleration. It was surprising to find that so simple a fact as this was not recognised by many engineers who otherwise were quite up to their business. For instance, they had cases where they were asked to supply a 10-H.P. motor which, under the specified conditions, was called upon to do 50 H.P. for an appreciable time in accelerating its own armature.

With regard to the question of the efficiency of motors, there were certain data necessary, as they were all aware, for finding the practical value of a motor. A very important element in the data for such calculations was the relation between the copper and iron losses. He thought that Mr. Field might have given them more information in this connection. To enable them to determine the iron losses in the case Mr. Field had mentioned, they wanted more details of the iron part of the core—as to what was the section of the core, etc. In reading a paper such as Mr. Field's it was necessary to its practical value to be given a section of the armature, the number and depth of the slots, and other particulars essential to a proper understanding of the electrical measurements.

With regard to controllers, he would like to ask if the author had found it necessary in his experience to use a magnetic blow-out, and also whether there was any one form of resistance which he found to be more effective than another. With regard to the motormen, it was quite evident to any one who watched these men manipulating their controllers that they were improving in their methods. Excellence in this respect was generally in inverse ratio to the amount of energy expended by the motorman. If they found a man perspiring over his handle, they might be sure that he was making the Pinkston Power Station perspire in the same degree. The introduction of electric traction into their city would be far more comprehensive in its effect than they yet imagined. It was a most important fact to electric manufacturers that there were five hundred men in their midst who had been taught to start and stop electric motors, and who were in possession of that rudimentary knowledge which was so necessary for the proper handling of their carefully designed apparatus. In conclusion he wished to thank Mr. Field again for the paper.

Professor Jamieson. Professor A. JAMIESON said, that the paper was well worthy of full reproduction in the Proceedings of the Institution, and they were fortunate in having had it read and discussed locally. He regretted

Professor Jamieson.

that the electric lighting fraternity were not better represented at the discussion. Mr. Mavor had just complained of the academic nature of Mr. Field's treatment of the subject, and of the want of detailed information regarding the design, materials, and proportions of several parts of the Glasgow tramcar motors; but he (the speaker) thought that Mr. Field had stuck very fairly to his text, and that he was right in not wandering into these bye-paths. As it was, Mr. Field had placed before them a new and thoroughly practical method of testing tramway motors, with an investigation into their characteristic properties. He not only gave diagrams of how the motors were connected mechanically and joined up electrically, for his tests, but he supplied data and examples whereby any one could at any time reproduce these tests. He had, in fact, gone a step in advance of previous communications upon this subject to the Institution and also of the latest text-books. They were all naturally more or less greedy to obtain details of proportion and construction, but he assumed that Mr. Field's present object was, to show how he had aimed at ascertaining—

(1) What was the mean working effective current required for particular tramway routes, and as a whole for the Glasgow system, when supplied with a mean trolley-wire pressure of 500 volts.

(2) Which type of tramcar motor gave the greatest efficiency at that mean working current and not, as usually stipulated and tried, at a maximum working current.

(3) The conclusions arrived at from (1) and (2) by aid of calculations, diagrams, and characteristic curves, whereby a set of working rules may be drawn up and given to the "Wattmen" instructors, inspectors, and drivers, so that the current and hence the power, coal, and running expenses of the cars may be lessened.

By this happy combination of science and practice, Corporations could effect far greater savings than by any known method of keeping down the salaries of the employés. He (the speaker) would go even one stage further than Mr. Field proposed to do; he would offer special privileges and encouragement to those drivers who managed to work their cars with a minimum expenditure of power, wear, tear, and repair.

Further, he would have each car fitted with a self-recording watt-meter and *true* speed indicator that could not be tampered with. He would have the automatic records of each driver's run handed into the integrating differentiating clerk and tabulated by him at once. Finally, as soon as the authorities had begun to recognise that such a system of scientific and practical investigation was likely to lead to the most satisfactory results, he would apply for a regular testing car.

Mr. Field should be encouraged in this work which he had so well begun, by an expression of the hope that he may be able to travel in his "laboratory on wheels," duly recording automatically and simultaneously, not only the speeds, voltages, currents, watts, gradients, torques, tractive efforts, and changes of accelerations, but even the varying coefficients of rail friction in the grimy, changeable atmosphere of Glasgow. He hoped that Mr. Field might thereby so reduce the working expenses as to induce extensions to be made to Clyde-side

Professor Jamieson. districts, where villas would soon spring up, and thus be no longer regarded as mere summer retreats for the privileged classes, but as residences for the weary, hard-working masses of this industrial centre.

Mr. Hird. Mr. W. B. HIRD said that the remarks which Mr. Field had made with regard to the paper had caused him (Mr. Hird) considerable discomfort, more especially his explaining away of the difference between the 250- and the 500-volt curves which he had shown at a previous meeting. Mr. Hird had tried to discover how this difference arose, and he thought that he had done so, but now Mr. Field came and told them there really was no difference. Perhaps Mr. Field would be able to throw some further light on this point.

Mr. Tidd. Mr. E. GEORGE TIDD asked Mr. Field whether the results shown in Fig. 14 were a matter of common knowledge among traction engineers, or whether Mr. Field's own recent investigations had brought them to light in such a forcible manner. It seemed to him (Mr. Tidd) that the amount of power which was shown to be required per car was a very small fraction of the total amount of power which would be used if the motors were running at full load the whole time; that without investigations such as Mr. Field had carried out engineers were very liable greatly to over-estimate the amount of power required. Did this surplusage account for the excess of plant which they all knew the Tramways Department had at Pinkston? He must add his congratulations to those of the other speakers, both to Mr. Field for the paper and the Local Section for having had it placed before them.

Mr. McWhirter. Mr. W. McWHIRTER said that in his opinion there was not much to discuss in the paper now before them, but they might be able to elicit further information upon various points. The very high heating factor allowed for tramway motors must have appealed to many of those present, and it had always appeared to him something requiring further information, viz., the rating of such motors weighing complete about 1,800 lbs. with a speed of about 400 revolutions per minute and working up to 35 H.P. It was evident that it was only in motors such as those used for tramway haulage that it would be practicable to allow a rise of temperature of 75° C., as under regular working conditions such a rise would very soon mean destruction to the motor. When compared with the Admiralty rise of 75° F., the above rise was almost double. The taking of temperature of motors and dynamos by means of thermometers generally gave only a rough approximation, and no doubt Mr. Field's suggestion to insert the thermometers through a hole in the casing would be an improvement. He (Mr. McWhirter) had, however, for many years used for this purpose small maximum thermometers like those used for clinical purposes. These could be secured inside the motor, in what was supposed to be the hottest position, and could remain there until the tests were completed, when the thermomometer would show the highest temperature obtained. Even this, however, was far from giving the real temperature within the coils of the motor, which might be from 30° to 60° F. higher than the temperature measured by thermometer. This, of course was easily ascertained by taking the resistance of the coil (the temperature of

which was required) when cold, and again when hot, and applying the usual temperature coefficient for copper. Mr. McWhirter.

Mr. Field gave an illustration of the "Prony Brake," and showed how it could be applied in the testing of tramway motors. Speaking as one of those who made many tests with this brake in the early eighties, he (Mr. McWhirter) could not advise the use of this apparatus, as it was most unsatisfactory and unreliable in every way. The brake-power, however, could be very easily ascertained by means of the rope-brake which had come so largely into use. This brake not only gave accurate data, but was further a pleasure to work with.

On page 1295 Mr. Field had given them the different tractive states of rails under various conditions. He would like to ask Mr. Field if these figures were the result of his own observation, and if not, perhaps he would kindly quote his authority for them, as that would no doubt add to their value. The figures given by Mr. Field on page 1298, showing the periods during which the motor controllers were on different notches were very interesting, but it would make them more useful if the method used in obtaining the results were given, and further, if it were explained how far these results would be affected by different states of weather. It must, of course, be apparent to every one that results obtained on a dry, dusty day would be very different from those obtained during heavy rain, when one could imagine the rails would be in the very best condition.

Mr. M. B. FIELD (*in reply*) said: Mr. Mavor's remarks very much surprised me, and I think, if he will forgive my saying so, that his comments are somewhat beside the mark. He seems to consider that because I am an official of the Corporation Tramway Department, it is incumbent upon me to give away any or all details of design or construction of machinery with which I, in my official capacity, have to deal. I would remind Mr. Mavor in the first place that I am reading this paper at the invitation of the Institution of Electrical Engineers, and in so doing am acting in purely a private capacity; secondly, the paper was not *intended* to deal either with the principles of design or construction, but with "Methods of Testing" and a "Study of the Characteristics of Tramway Motors," and I think, all things considered, it would, under these circumstances, have been a mistake to digress into constructive details or into the principles of design. Mr. Field.

Mr. Mavor dealt at some length with the relation of the copper to the iron-losses in motors. In dealing with shunt-wound motors this idea is usually expressed as the relation of the variable to the fixed losses. For shunt-wound motors this ratio at full load is of the greatest importance, and it is perhaps even of greater importance still in dealing with alternate-current transformers. The proper proportioning of these two factors has a most weighty bearing upon the overall efficiency of the supply system taken as a whole. The same arguments, however, do not apply to *series* motors, as there are, strictly speaking, *no* fixed losses, the iron-losses varying with the load as is distinctly shown on the curves in the paper. Moreover, in the paper I have indicated a method whereby the iron, friction, and Foucault current losses may be separated. I

Mr. Field. stated that I have never had the spare time, nor for practical purposes found the necessity, for going into this refinement. It is, however, quite possible to carry it out for any one who has the leisure.

With regard to controllers, I might say that for ordinary street-car work the magnetic blow-out is by no means an essential feature. Excellent controllers with and without magnetic blow-out devices are now upon the market.

I have to thank Professor Jamieson for his complimentary remarks and suggestions, but think there is no direct criticism in his various comments to which I should reply.

Mr. Hird referred to the tractive effort curves at 250 and 500 volts. It will be remembered that on the diagram I showed at the last meeting I called attention to the fact that these two curves were not quite coincident, and the values differed by a greater percentage than one would expect. I suggested that perhaps some error had crept in in making the reductions to a standard voltage and temperature. To-night I was able to state that this was actually the case, and that the points of both curves were so near that it was not feasible to draw in two distinct curves at all. This is only natural. The tractive effort depends on the product of armature currents and magnetic field. Both of these are dependent only on the current flowing, and not on the supply voltage. The lost torque in hysteresis, gear, and friction should be the same in each case. In fact, the only item of difference would be the Foucault current back torque. At the lower speed the eddies would be of small magnitude, and their back torque consequently less. One would not expect, however, that they would have much effect upon the tractive effort curves. I would call Mr. Hird's attention to the fact that the efficiencies are different for 250 and 500 volts; the speeds are practically proportional to the voltage and to the efficiencies, the tractive effort in the two cases being the same. I think if Mr. Hird looks at the matter in this light he will not have any further difficulty.

Replying to Mr. McWhirter's remarks, I would say that I particularly pointed out in the paper that it is not feasible to work motors under conditions where the temperature rise would be 75° C.: this rise is only taken when rating a motor in order that it may be tested at a comparatively high overload such as it is often called upon momentarily to meet under normal conditions. If Mr. McWhirter refers to the thermal characteristic on page 1292, Fig. 9, he will see that the G.E. 58, rated on the one hour's basis at 2 H.P., will only give out 15 H.P. for two hours, and that with a rise of 75° C. working continuously with a normal temperature-rise, say 45° C., it would *probably* not give out more than 6–8 H.P. Clearly it would be absurd to rate it at only 8 H.P., when it must be strong enough mechanically, and the electrical design must be such, as to enable it to give out, if called upon to do so, from 30 to 40 H.P. Measuring the temperature by rise of resistance is, of course, quite a usual method. I frequently adopt it, and find that for armature coils the result agrees nearly with the thermometer, but for the field coils the thermometer gives a considerably lower result. The reason is, first, that the armature coils are thin and narrow, and are "backed-

up" by the armature teeth, in which a large amount of heat is generated. The whole surface of the armature has a tendency, therefore, to come to a more uniform temperature, and there is less opportunity for conduction from the centre of the coils outwards. With the field coils the reverse is the case. The heat is generated inside the coils only, and conducted and radiated away from the exterior, which is comparatively cool. The thermometer being placed at the exterior surface is really at the coolest part. I do not consider the Prony brake described as the best. I have used it, however, in connection with the testing frame as described, quite successfully as a check on the other results. As stated, I prefer the entirely electrical method. It is worthy of note, however, that the brake shown in the illustration can be used up to 100 H.P. The figures given in the paper for tractive effort that produces skidding on different classes of rail were given me personally by Mr. W. B. Potter, the American authority on electric railway work, about four years ago. I believe them to be very fairly representative. With regard to diagram Fig. 14, I assure Mr. McWhirter there is no difficulty whatever in taking the necessary readings. With a ruled log-sheet divided off into columns for the five different periods, one man writing down and keeping "one eye" on the controller while another man calls seconds (not time intervals) as the controller moves from position to position. The total current consumption per car-mile will undoubtedly depend on the weather, but it is doubtful whether the proportions of the journey spent in the five positions will do so, and to show these is really what the diagram has been constructed for. Mr Field.

Mr. Tidd asked various questions, in reply to which I would say that it is well known that each tramcar makes sudden and very fluctuating demands upon the system. It is fairly well known now by traction engineers how much current per car should be reckoned when laying down a system, provided the amount and number of grades be known approximately, and also the weight and style of the car. The results shown in Fig. 14 would naturally be different for every system and for every route in each system, and probably for every journey over each route. I must confess, however, that I was surprised at the result revealed by the diagram, particularly at the very small proportion of the time during which the motors are in full parallel. I think I am correct in saying that my method of testing has not been criticised by any of the speakers to-night. I would like to point out that the method for the separation of the iron and C^2R losses is applicable also to shunt-motors. If we were to take two shunt-motors, run them light, and, if necessary, adjust one field till they ran at exactly the same speed (*i.e.*, till they have exactly the same field-strength), and note the shunt-current in each case; then belt them together or, better, gear them, and separately excite with the above found currents; we should then know that the hysteresis, friction, windage, etc., would be the same for each; subtracting the known armature C^2R losses from the difference of input and output of the combination (when tested in a similar manner to that described for

Mr. Field series-motors), halving the results, and crediting half to the motor and half to the generator, the efficiency would be easily found. The Foucault current, hysteresis, and friction, could then be separated out as indicated above. If this method were to be adopted, slip of the belt should be eliminated as far as possible, but in any case the nett error this would make in the efficiency would be very small. This may be a method already in vogue. I am not, however, aware that it is, and I call attention to it here for what it is worth.

REPORT OF A DEPUTATION FROM THE INSTITUTION OF ELECTRICAL ENGINEERS TO THE PRESIDENT OF THE BOARD OF TRADE ON THE SUBJECT OF LEGISLATIVE RESTRAINTS ON ELECTRICAL ENTERPRISE.

Wednesday, June 18, 1902.

The Deputation was received by the Right Hon. Gerald Balfour, M.P., President of the Board of Trade, and included besides Mr. James Swinburne, President, Lieut.-Col. R. E. Crompton, C.B., Messrs. S. Dobson, S. Z. de Ferranti, Sir Michael Foster, Secretary R.S.; the Right Hon. Lord Greenock, the Right Hon. Lord Kelvin, G.C.V.O., F.R.S., Messrs. H. E. Harrison, J. E. Kingsbury, H. Lea, W. L. Madgen, H. A. Mavor, W. M. Mordey, S. Morse, W. H. Patchell, J. Perry, F.R.S., the Right Hon. the Earl of Rosse, Messrs. R. P. Sellon, C. E. Spagnoletti, C. P. Sparks, A. A. C. Swinton, Silvanus P. Thompson, F.R.S., R. Spence Watson, Major-General C. E. Webber, C.B., and Sir Thomas Wrightson.

The Right Hon Lord Kelvin having introduced the Deputation,

Mr. JAMES SWINBURNE, President, said :—

Sir,—The Council of the Institution of Electrical Engineers formed a Committee a little while ago to advise them whether they should take any action that would assist the electrical industry in connection with the legislation that especially concerns it. This Committee asked various prominent people to give evidence, and included in their invitation prominent exponents of municipalisation as well as of individualism. Their report is before you, and speaks for itself.

On receipt of this report the Council asked Lord Salisbury to receive a deputation on the subject of the effects of legislation on electrical enterprise. He replied that he concurred in thinking it desirable that His Majesty's Government should be put in possession of the views of the Council of the Institution, and that, as the matters almost all fall within the cognisance of the Board of Trade, it was desirable that the deputation should be addressed to you.

We therefore come to you, Sir, not only as President of your Department, but as a member of His Majesty's Government, and we ask you to be kind enough to communicate the results of this conference to the Cabinet.

Twenty years ago the distribution of electrical energy for lighting became practical, but even electrical engineers only considered distribution over comparatively small areas. As the distribution involved underground wires and the opening of streets, the local authorities had to be considered, as they have to do with streets. It is merely through this accident as to control of streets that the local authorities have become involved in the electrical industry. If it were not for the question of control of streets and therefore also of tramways, local authorities would have no more to do with distribution of electrical energy than of bread, meat, coals, clothes, wine, newspapers, or any

other commodity. The almost accidental circumstance of electric distribution needing wires has thus involved electrical distribution in the most complicated legal relations with local authorities. In 1882 it was not contemplated that a station would distribute over more than a parish or part of a parish; and the Electric Lighting Act was drawn on parochial lines. But there was more than this. So tender was Parliament of the interests of local authorities that they were given an option of purchase of local undertakings at the end of twenty-one years. Thus the private companies were to take all the risk, and the local authorities all the benefits. This discouraged the industry, until it was to some extent relieved by having the twenty-one years extended to forty-two.

But since 1882 the industry has advanced. Electrical engineering no longer deals with small areas of a few acres. We now deal with areas of a thousand square miles and upwards, covering not only parishes but counties. We deal with electrical tramways or street railways which connect town with town and district with district. But we are hampered with parochial legislation. We hold that electrical enterprises should have their limits and boundaries set by economical considerations only, and that arbitrary boundaries, mostly of mediæval ecclesiastical origin, should not limit the distribution or the growth of electrical systems. Apart from the questions of fairness, the purchase clauses are entirely out of date now, and are becoming as inapplicable to electrical undertakings as to railway systems.

We do not come before you to oppose municipal trading. I wish to put that to you very strongly. It is not our business as an Institution to go into such a political question as municipal trading. We have no mandate to that effect. We cannot oppose from that point of view. But what we do earnestly ask to have checked is the abuse of their legal powers by local authorities. We want to see the electrical industry flourish here as elsewhere, and we want to see ratepayers obtain the best thing available. Their interest is the industry's interest. We want to prevent the injudicious action of local authorities in opposing electrical progress because they have already risked ratepayers' money in gas works, or preventing ratepayers getting the advantage of supply from a power company because the authorities have invested in their own electric supply. We want to prevent the pure unreasoning obstruction by local authorities who get orders themselves and do not work them, preventing others coming in, and where Companies do the same thing we want to oppose their action also.

We urge that local authorities should not have power to prevent schemes even coming before Parliament on their own merits.

As to compulsory purchase, we urge that that is now only a legal incubus on the industry. As systems extend over larger and larger areas the difficulties are greater, and the laws so little fit the circumstances, that there is really no saying what an undertaking is liable to at the end of the term. We would urge that there is no more justice in compulsory purchase of electrical systems than of other local industries. The control of roads and streets is a distinction, not a difference that puts electrical distribution on a different footing as

regards monopoly from, say, coal supply; nor does it make electric tramways any more a monopoly than omnibuses.

We would also ask—and in this other industries would no doubt join us—for simpler, more efficient, and less costly procedure in connection with Parliamentary Committees. We only represent a small part of the engineering industries that are hampered by the expense and inefficiency of Parliamentary procedure generally; but if it is indeed hopeless to improve the working of the Committee system generally, we only ask for such facilities as can be easily granted as regards electrical bills.

So far I have dealt with matters concerning the Government generally; I will now deal with the Department of which you, Sir, are the head. With the officers and electrical inspectors of the Board of Trade we are well satisfied, but we have not enough of a good thing. It is not for us to say how it should be done; we suggest, however, a more liberal supply from the Treasury to enable you to have a larger electrical staff. The organisation of the Board of Trade does not seem quite perfect. The electric light even of inland towns comes under Fisheries and Harbours, perhaps because it was originally used in lighthouses; and electric traction comes under Railways. The regulations are behindhand. For instance, the tramway regulations were drawn up when only small systems were contemplated, and now urgently require revision. We ask to have the question of permitting overhead wires opened again. We ask that the overhead systems used for tramways at 500 volts should in some cases be available for lighting. We ask for re-opening of the question of overhead wires generally. The limits of size of converters and trunk mains also require revision. Should your Department care to avail itself of the help of the Institution in discussing regulations, it is at your service.

Though we urge certain improvements in your Department, we are very much more concerned in the broader question of the effect of legislation on our industry.

We feel very deeply that the effect of legislation on our industry has been very repressive. Electrical science has always been well ahead in this country, but the industry has lagged behind compared with other countries, and with other industries in this country.

As to whether municipal trading is good or bad in itself we say nothing. But through the fact that, though they do not own them, the local authorities control the streets and roads, our industry has become tangled up with municipalisation. If municipal trading is a good thing when worked properly we are anxious to help it as we receive most benefit from it; but if it is a bad thing our industry is the chief sufferer. Municipalisation may be a good thing if carried out on sound principles, but without complaining of it, we feel that the powers of local authorities are capable of very serious abuse. We think, therefore, the effect of municipal trading as far as it concerns us should be investigated, so that His Majesty's Government may know whether it is a good thing, not for municipalities considered alone, but for the community at large, having regard to questions of engineering, local

indebtedness, housing, rapid transit, and concentration in cities. We ask you, therefore, to do what is necessary to cause the appointment of a Royal Commission to consider the whole question of electrical legislation.

Lieut.-Col. Crompton, Dr. R. Spence Watson, Mr. S. Morse, Sir Michael Foster, Mr. S. Z. de Ferranti, Mr. W. H. Patchell also spoke.

Mr. Swinburne having then suggested that the question of the Board of Trade Regulations would be amply met if the Institution could examine into them thoroughly, and Mr. Balfour having expressed his assent to this course,

Mr. BALFOUR replied that he fully recognised the great importance of the subject, and to a very large extent was in sympathy with much that the Deputation had brought before him. He thought it was undeniable that electrical industry in this country was behindhand as compared with America and Germany, but doubted whether that backwardness was due altogether to defects in legislation, or to regulations of an oppressive character, or to the abuse of power by local authorities. America was a new country, very sparsely inhabited, and with comparatively few established interests to contend with; whereas this was an old country with a very dense population, and a large number of strongly established interests which produced a very strongly developed instinct of conservatism. He believed that it was those fundamental conditions rather than any actual legal enactments which had tended to retard the development of the electrical industry in Great Britain. But while he held that view, he did not for a moment contend that changes in the direction indicated by the Deputation might not be of a very beneficial character. It appeared to him that the chief question was really the power which the legislature had given to the local authorities to veto schemes.

In the case of electric traction, local authorities appeared to have, under the Act of 1870 and the Standing Orders of the House of Commons, an absolute veto with regard both to Provisional Orders and to Bills, but to some extent the evils flowing from that condition of things had been remedied by the adoption, in many cases, of Light Railways procedure, even when the scheme was really for a tramway. It was true that the Light Railway Commissioners and the Board of Trade had considered themselves more or less bound by the regulations laid down in the Tramways Act and in the Standing Orders of the House of Commons. He did not think they had gone the length of giving the local authority an absolute veto, but undoubtedly they were influenced by the legislative provisions he had mentioned. The subject of traction had been investigated by a Departmental Committee appointed by the Board of Trade, and as a result of the deliberations of that Committee a Bill had been drafted which he thought would go very far to meet all the reasonable objections that had been urged against the present powers of the local authorities. But it was idle to conceal the fact that the local authorities represented a very great power in this country, and conceived it strongly to their interest to possess, if not an absolute veto, at all events a *locus standi* which would enable them to make their views powerfully felt.

With regard to electric supply, the case was somewhat different. Where an enterprise for such a purpose was prompted by Bill he believed Parliamentary Committees now usually acted upon the recommendation of the Committee of 1898, but legislation would be required in order to enable the Board of Trade to act upon the recommendations of that Committee in respect to Provisional Orders, and a Bill was also ready to give effect to the recommendations of that Committee. He could not hold out much hope that either Bill would be passed during the present Session, which was well occupied with important measures; but it was the desire of the Board of Trade, when opportunity offered, to press forward both measures. The Board of Trade would be always happy to listen to any suggestions that came from so important a body as the Institution of Electrical Engineers, and was as anxious as the Institution to secure that the public interests should be properly served by the development of the great industry which the Deputation represented.

With regard to the appointment of a Royal Commission, that was a subject for the Cabinet, and he would consult his colleagues on the matter, but he must not be understood to pledge himself to recommend that a Commission should be appointed. In conclusion, the President promised to consider the question of strengthening the Board of Trade staff.

The Deputation, having thanked the right honourable gentleman, withdrew.

The Thirtieth Annual General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 22nd, 1902, Mr. WILLIAM E. LANGDON, President, in the Chair.

The minutes of the Ordinary General Meeting held on May 15th, 1902, were read and confirmed.

The names of new candidates for election into the Institution were announced, and the President stated that the present meeting being the last of the Session, these candidates would, in accordance with the Articles of Association, be balloted for that evening.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Sidney Smith.

From the class of Associates to that of Members—

T. Herbert Minshall.

From the class of Associates to that of Associate Members—

Arthur William Fithian.

From the class of Students to that of Associates—

Anthony Marinier. | Harry Turner Tovey.

Messrs. J. A. Ornstein and J. T. Morris were appointed scrutineers of the ballot for the election of new members.

Donations to the *Library* were announced as having been received since the last meeting from Mons. C. Guilbert; to the *Building Fund* from Mr. G. F. Möller; and to the *Benevolent Fund* from Mr. R. W. Weekes, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: I have also to announce that the Dublin Local Section has sent to the Institution a likeness of the late Professor Fitzgerald, a very graceful act on their part which we shall, of course, acknowledge in the ordinary course. We are very much indebted to the Dublin Local Section for their gift.

The thanks of the meeting were accorded to the Dublin Local Section for their donation.

The SECRETARY read the Annual Report of the Council :—

REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING ON MAY 22ND, 1902.

LOCAL SECTIONS.

No new Local Sections have been created during the year under report, but an increasing amount of valuable work is being done in those previously established. Many of the papers read have been of a high order of excellence, and the discussions that have taken place have been both successful and interesting.

The Council gladly avails itself of this opportunity to place on record its hearty thanks for the great assistance rendered by the Glasgow Local Section in the arrangements for the work undertaken by the Institution in connection with the International Engineering Congress, held at Glasgow in September, 1901, further reference to which is made hereafter.

ELECTIONS AND TRANSFERS.

The Council has had the pleasure of electing Signor Pacinotti an Honorary Member during the present year.

Notwithstanding the increased stringency of the Articles of Association relating to qualifications for membership, the increase in membership during the past twelvemonth has been most remarkable; there have been elected during this period 26 Members, 126 Associate Members, 183 Associates, 203 Students; making a total of 538. 42 Candidates have also been approved for ballot to-night.[1]

24 Associate Members, 1 Foreign Member, and 12 Associates of the Institution have been transferred to the class of Members, whilst 64 Associates and 1 Member of the late Northern Society have been transferred to the class of Associate Members, and 95 Students of the Institution have been transferred to the class of Associates. At the beginning of the current year, the Manchester Society of Junior Electrical Engineers was merged in the Institution, as a Students' Section of the Manchester Local Section. Those of its members who did not already belong to the Institution were duly proposed and admitted, according to the prescribed methods of election, as Students of the Institution.

DEATHS AND RESIGNATIONS.

The Council has to record with extreme regret the loss to the Institution by death of 1 *Local Honorary Secretary*, Dr. C. Lemon; 12 *Members*, W. D. Bailey, A. S. Bolton, G. L. Bristow, E. W. Buller, W. T. Goolden, Matthew Gray, J. Howe, J. Slater Lewis, H. R. Low, C. W. Lundy, J. Neale, H. D. Norman; 2 *Associate Members*, G. A. Clark, J. M. G. Wilson; 1 *Foreign Member*, Jules Wünschendorf; 5 *Associates*, R. Bayly, F. M. Hartley, J. Kemsley, Commander Clifton Sclater, F. H. Wilson; and 1 *Student*, E. Amos.

[1] As these candidates were all duly elected, the numbers representing additions to the Register since the Annual General Meeting in 1901 were, at the end of the meeting, as follows:—Honorary Member, 1; Members, 27; Associate Members, 131; Associates, 197; and Students, 225.

Two Members, 1 Associate Member, 6 Foreign Members, 16 Associates, and 9 Students have resigned since the date of the last Report.

PAPERS.

In addition to the President's Inaugural Address, the following papers, read at Ordinary and Extraordinary General Meetings, including the International Engineering Congress, Glasgow, 1901, will have been published in Volume 31 of the Journal :—

DATE, 1901.	TITLE OF PAPER.	NAME OF AUTHOR.
	INTERNATIONAL ENGINEERING CONGRESS, GLASGOW.	
Sept. 3.	—Introductory Address of the Chairman of Section IX.	W. LANGDON, Member.
„ 3.	—"Notes on some of the Chief Objects of Interest to Electrical Engineers in the Glasgow International Exhibition, 1901"	W. B. SAYERS, Member
„ 4.	—"High-Speed Railway Car of Allgemeine Elektricitäts Gesellschaft, Berlin"	O. LASCHE.
„ 4.	—"Dangers from Trolley Wires and their Prevention"	Prof. A. JAMIESON, Member
„ 4.	—"Electricity Supply Meters of the Electrolytic Type"	J. R. DICK, Member.
„ 4.	—"Kelvin's Electric Measuring Instruments"	Prof. M. MACLEAN, Member.
„ 5.	—"The Relative Advantages of Three-, Two-, and Single-Phase Systems for Feeding Low-Pressure Networks"	M. B. FIELD, Member.
„ 5.	—"Modern Commutating Dynamo Machinery with Special Reference to the Commutating Limits"	H. M. HOBART, Member
„ 5.	—"Design of Continuous-Current Dynamos."	H. A. MAVOR, Member.
	ORDINARY GENERAL MEETINGS.	
Nov. 28.	—"A Permeameter for Testing the Magnetic Qualities of Metals in Bulk"	C. V. DRYSDALE, Member.
„ 28.	—"The Physical Properties of Certain Aluminium Alloys, and some Notes on Aluminium Conductors"	Prof. E. WILSON, Member.
Dec. 12.	—"Some Principles Underlying the Profitable Sale of Electricity"	A. WRIGHT, Member.
1902.		
Jan. 9.	—"Reports of Committees on the Institution Visit to Germany in 1901 :— Of the Committee on Traction, Light, and Power Distribution. Of the Committee on Manufacturing. Of the Committee on Telegraphs and Telephones.	
„ 23.	—"Earth Currents derived from Distributing Systems"	E. B. WEDMORE, Associate Member.
Feb. 13.	—"Researches on the Electrical Conductivity and Magnetic Properties of upwards of 100 different Alloys of Iron"	Prof. W. F. BARRETT, Member.
„ 27.	—"Electric Shock and Legislation Thereon" ..	Major-Gen. WEBBER, C.B., Member.
„ 27.	—"Electric Shocks"	F. B. ASPINALL, Member
„ 27.	—"Electric Shocks at 500 Volts"	A. P. TROTTER, Member

Date, 1902.	Title of Paper.	Name of Author.
Mar. 20.—	"Problems of Electric Railways"	J. SWINBURNE, Member, and W. R. COOPER, Associate Member.
May 1.—	"Automatic Relay Translation for Long Submarine Cables"	S. G. BROWN, Associate Member
„ 15.—	"Electrical Traction on Steam Railways in Italy"	Prof. C. A. CARUS-WILSON, Member.

And the following papers, selected from those read at the meetings of Local Sections, have been, up to the present, accepted for publication [1] :—

BIRMINGHAM LOCAL SECTION.

Date.	Title.	Author.
1901.		
Nov. 27.	Inaugural Address of the Chairman	Prof. O. LODGE, Member.
Dec. 11.	"Note on Alternate-Current Diagrams." "The Testing of Motor Losses"	Dr. W. E. SUMPNER, Member.
1902.		
Jan. 22.	"Surface-Contact System of Electrical Traction" (abstract)	W. KINGSLAND, Member.

CALCUTTA LOCAL SECTION.

1901.		
Mar. 29.	"Insulation of Conductors of Electricity in India"	K. A. SCOTT-MONCRIEFF, Member.
April 19.	"Hints on Overhead Construction"	O BURNE, Associate.

CAPE TOWN LOCAL SECTION.

Dec. 2.	"Note on Electrical Engineering Practice in Europe and America"	J. DENHAM, Member.

DUBLIN LOCAL SECTION.

Nov. 14.	"An Account of the Visit of the Institution to Germany, June, 1901"	P. S. SHEARDOWN, Associate Member.
Dec. 19.	Inaugural Address of the Chairman	Prof. W. F. BARRETT, Member.
April 18.	"Note on a Humming Telephone"	F. GILL, Member.
1902.		
Feb. 13.	"Notes on Irish Water-Power and its Electrical Development"	W. TATLOW, Associate Member.

GLASGOW LOCAL SECTION.

1901.		
Nov. 19.	Inaugural Address of the Chairman ..	Prof. M. MACLEAN, Member.
Dec. 10.	"Aluminium; Notes on its Properties, Production, and Uses"	W. M. MORRISON, Member.
1902.		
Jan. 14.	"Practical Notes on Continuous-Current Distribution Mains"	J. C. A. WARD, Associate.

MANCHESTER LOCAL SECTION.

1901.		
Nov. 19.	Inaugural Address of the Chairman	C. H. WORDINGHAM, Member.

[1] The printing of the following Papers has since been ordered :—
DUBLIN : "Lighting and Driving of Textile Mills by Electricity," by M. OSBORNE (May 29th).
GLASGOW : "Notes on the Testing of Tramway Motors, and an Investigation into their Characteristic Properties," by M. B. FIELD (April 8th).
NEWCASTLE : "The Equipment of a Modern Telephone Exchange," by F. A. S. WORMULL (February 17th).

Date.	Title.	Author.
1901.		
Dec. 17.	"The Breaking of Shafts in Direct-Coupled Units due to Oscillations set up at Critical Speeds	J. Frith, Associate Member; E. H. Lamb.
1902.		
Jan. 28.	"The Supply of Electricity in Bulk"	H. A. Earle, Member.
Feb. 18.	"The Construction of High-Tension Central Station Switch Gears with a Comparison of British and Foreign Methods"	H. W. Clothier, Associate Member.
Mar. 18.	"Some Points in the Equipment of Electric Tram Cars" (abstract)	W. G. Rhodes, Member.

Newcastle Local Section.

1901.		
Nov. 18.	Inaugural Address of the Chairman	J. F. C. Snell, Member.
Dec 16.	"Electrical Car Equipments and their Maintenance" (abstract)	A. W. Wigram, Associate.
1902.		
Jan. 13.	"Starting Resistances" (abstract)..	Arthur E. Gott, Associate Member.
Jan. 27.	Some Notes on the Influence of the Sub-Station Equipment and Transmission Line on the Cost of Electricity Supply..	Andrew Stewart, Associate.

The Council, owing to the illness of the authors, or to causes over which they could exercise no control, has had to defer several papers which had been definitely promised for reading during the session now ending. Several of these papers promised to be of special interest, but it is hoped that they will yet find a place in the proceedings of the Institution.

The Institution with pleasure again records its indebtedness to the Institution of Civil Engineers, and to the Society of Arts, for the continuance of their generous hospitality in allowing their rooms to be used for General Meetings of the Institution.

Publications of the Institution.

The contents of the Journal, already largely extended by selected papers read at various Local Sections, has been still further increased by the publication of a special number devoted to the report of the proceedings of the Electrical Section of the International Engineering Congress in Glasgow.

The General Index of Vols. 21–30 referred to in last year's report was issued in August, 1901, simultaneously with the last number of the Journal to which it referred.

The Council has decided that as the current year's volume is the first of a new ten-year period, the system of indexing the Journal might with advantage be revised. The index will, therefore, in future be somewhat extended, fuller references being given to subjects of importance incidentally introduced in papers and discussions.

In collaboration with the Physical Society, the publication and issue to the members of the Institution of *Science Abstracts* has been continued, and the Council believes that the usefulness of the publication

is more than fully maintained. It was with great regret that the Council learnt that Mr. W. R. Cooper was no longer able to devote the time necessary to the editing of the Abstracts, and that he therefore felt himself compelled to resign the Editorship in December, 1901. They heartily recognise the great indebtedness of the publication to his able management during the three years he held the office. They are glad to report that he has accepted nomination as one of the representatives of this Institution on the Executive Committee of Science Abstracts, the other representative appointed being Mr. H. E. Harrison. The Committee of Science Abstracts has appointed Mr. G. W. de Tunzelmann, a member of this Institution, Editor in Mr. Cooper's place.

The publication of the following papers in the Journal as Original Communications has been approved :—

"Note on Duplexing of Cables"	H. KINGSFORD, Member.
"The Capacities of Polyphase Cables"	A. RUSSELL, Member.
"The Rise of Temperature in the Field Coils of Dynamos"	E. BROWN, Student.
The Application of Electric Power to Machine Tools" (Abstract of Students' paper)	C. B. NIXON, Student.
"The Limitations of Graphical Methods in Electrical Theory"	A. RUSSELL, Member.
"Note on an Observed Effect of Lightning Discharge on Birds in Mid-air"	L. JOSEPH, Associate-Member.
"A General Formula for Regular Armature Windings"	D. ROBERTSON, Associate.
"A Method of Studying Armature Windings by means of Winding Diagrams"	D. ROBERTSON, Associate.
"Sparking in Switches"	ALEXANDER RUSSELL, Member, and CLIFFORD PATERSON.

ANNUAL PREMIUMS.

The Council has awarded the following premiums for papers and communications :—

The INSTITUTION PREMIUM, value £25,

to Mr. O. LASCHE, for his Glasgow Congress Paper on "The High-Speed Railway Car of the Allgemeine Elektricitäts Gesellschaft."

The "PARIS ELECTRICAL EXHIBITION PREMIUM," value £10,

to Mr. H. W. CLOTHIER, for his paper before the Manchester Section on "The Construction of High-Tension Central Station Switch Gears, with a comparison of British and Foreign Methods."

The "FAHIE PREMIUM," value £10,

to Mr. S. G. BROWN, for his paper on "Automatic Relay Translation for Long Submarine Cables."

An Extra Premium, value £10,

to Messrs. J. Frith & E. H. Lamb, for their paper before the Manchester Local Section on "The Breaking of Shafts in Direct-Coupled Units due to Oscillations set up at Critical Speeds."

Two Extra Premiums, value £5 each,

respectively, to Mr. H. M. Hobart for his Glasgow Congress paper entitled "Modern Commutating Dynamo Machinery, with Special Reference to the Commutating Limits"; and to Mr. K. A. Scott-Moncrieff for his paper before the Calcutta Local Section on "The Insulation of Conductors of Electricity in India."

A Premium," value £10,

to Mr. David Robertson, for his Original Communication entitled "A Method of Studying Armature Windings by means of Winding Diagrams."

A Premium, value £5,

to Mr. A. Russell, for his Original Communications entitled, "The Capacities of Polyphase Cables"; "The Limitations of Graphical Methods in Electrical Theory."

Students' Premiums.

1st Students' Premium, value £7, to Fielder J. Hiss, Junior, for his paper entitled, "Some Notes on Modern Continuous-Current Dynamo Design."

2nd Students' Premium, value £5, to Philip A. Laubach, for his paper on the "Wehnelt Interrupter."

3rd Students' Premiun, value £5, to Ernest William Short, for his paper on the "Electrical Equipment of Printing Machinery."

An extra Students' Premium, value £3, to S. E. Glendenning, for his paper on "Continuous-Current Testing."

Papers other than those of the Students' Section which were not in type by April 30, 1902, were reserved for consideration in awarding premiums in 1903; but certain papers, which were received too late for consideration in 1901, have been taken into account in making the present award.

Salomons Scholarship.

The Council has awarded the Salomons Scholarship, value £50, to Mr. Philip A. Laubach, of the Finsbury Technical College.

David Hughes Scholarship.

The David Hughes Scholarship, value £50, has this year been

awarded by the Council to Mr. EDWARD FISHER, of the Finsbury Technical College.

STUDENTS' CLASS.

Following the precedent of 1900, the Council invited reports from Students in connection with the Glasgow Exhibition of 1901. Certain classes of Electrical Exhibits were selected, and every Student was invited to name two or more of these classes of exhibits on which he would be prepared to submit a report. One of these subjects was allotted to each Student who responded to the invitation. It was understood that the writers of the best ten reports sent in, as adjudicated upon by the Council, should receive, each, a premium of £5. Thirty-one reports in all were received, and a premium of £5 has been awarded to each of the following Students :—

NAME.	SUBJECT FOR REPORT.
ATCHISON, A. F. T. ..	"Gas and Oil Engines Suitable for Electrical Generators."
DAVIES, T. A.	"Electric Generators and Transformers."
GRIFFIN, J.	"Materials used in Secondary and Primary Batteries."
LANGFORD, J. B.	"Electrical Measuring Instruments."
LAUBACH, P.	"Electric Generators and Transformers."
PERCY, H. L.	"The Special Fittings of Electric Cars, and for Electric Traction generally, including the Poles for Trolley Wires."
RAWORTH, A.	"Steam Engines Driving Generators."
REID, D.	"The Special Fittings of Electric Cars, and for Electric Traction generally, including the Poles for Trolley Wires."
ROBINSON, F. E.	"Labour-saving Apparatus and Machine Tools worked with Electrical Energy."
SMAIL, J. C.	"The Electrical Driving of Lifts, Fans, and Pumps."

Twelve meetings of the Section have been held during the Session, and the average attendance at the meetings has shown a marked increase. The Council is much indebted to the members of the Institution who have kindly presided on these occasions.

Visits to the following places were, at the request of the Students' Committee, arranged for the Students by your Secretary, during the year, and the Council desires to record its indebtedness to the various firms and gentlemen who have so kindly given facilities to the Students to visit their works :—

The Central London Railway.
The City and South London Railway.
The City of London Electric Lighting Company, Limited.
Messrs. Easton & Co., Limited.
The Electrical Power Storage Company, Limited.
Messrs. Elliott Brothers.
The Fulham Electricity Supply Works.
The Incandescent Electric Lamp Company, Limited.
The India Rubber, Gutta Percha, and Telegraph Works Company.
The London Electric Supply Corporation, Limited.
The London United Tramways, Limited.

The Metropolitan Electric Supply Company, Limited.
Messrs. Siemens Bros. & Co., Limited.
The Thames Iron Works and Shipbuilding Company, Limited.

During the Easter holidays a visit of the Students to the Newcastle district was paid; thirty-two Students took part, and during the five days of the visit the following works and installations were visited, and to these firms also the Council records its thanks:—

Messrs. Armstrong (Sir W. G.) Whitworth & Co., Limited.
Messrs. J. H. Holmes & Co.
Newcastle and District Electric Lighting Company.
Newcastle Electric Supply Company, Limited.
Palmer's Shipbuilding and Iron Company, Limited.
Messrs. Ernest Scott & Mountain, Limited.
Stockton-on-Tees Corporation Electricity Works and Three-Phase Tramway System.
Sunbeam Lamp Manufacturing Company, Limited.
Sunderland Corporation Electric Light and Tramway System.
Sunderland Forge and Engineering Company, Limited.

The Council congratulates the Students' Committee and its Hon. Secretary, Mr. H. D. Symons, on the success achieved.

Sectional Committees.

The Council again calls attention to the appointment of the Sectional Committees representing the following interests respectively:—

(1) Traction, Light, and Power Distribution.
(2) Telegraphs and Telephones.
(3) Manufacturing.
(4) Electro-Chemistry and Electro-Metallurgy.

It reminds the members that these Committees have been constituted partly for the purpose of affording convenient channels through which they may bring to the knowledge of the Council any questions affecting the several branches of Electrical Engineering that they may think require special consideration. The Council would point out that the constitution of these Committees is regularly shown in the List of Members, and will in future be printed in the opening pages of the Journal.

Annual Dinner.

The Annual Dinner was held on December 9th, in the Grand Hall of the Hotel Cecil, and was well attended, the number present exceeding 300.

Annual Conversazione.

The Annual Conversazione was again held on June 14th, by the kind permission of the Trustees of the British Museum, in the Museum of Natural History, South Kensington, and was in every way a most successful reunion.

Annual Accounts and Financial Position.

The very rapid development in the work of the Institution that has taken place during the past few years has led to an increase in expenditure that is only partially compensated for by the growth of the revenue and the results achieved.

Considering, however, that there were several special expenses that may be fairly considered abnormal, incurred during the financial year under consideration, the Council is gratified in being able to report a surplus of £758 2s. on the year's work.

It should further be observed that the surplus would have been greater this year had it not been that a sum of £84 was written off for depreciation on books, pictures, and furniture. No allowance is made in the accounts for the value of books and pictures presented to the Institution, which might otherwise have been estimated at £40.

The sum of £30 12s. 3d. has been invested on account of Life Compositions, leaving £16 7s. 9d. still uninvested on December 31st.

The estimated realisable amount of subscriptions outstanding on the 31st of December was £375, and of this over £210 has since been received.

Building Fund.

This Fund still continues to progress steadily, having risen from £8,421 in December, 1900, to £9,398 in December, 1901. Further contributions from members, and a further addition from the General Funds of the Institution during the early months of 1902, have brought the fund up to £10,000 at the date of this report. Of the increase since December, 1900, over £880 has been derived by contributions from the Institution. It is very desirable that this Fund should meet with the the liberal support of the members, and your Council strongly urges the propriety of all classes contributing annually towards it.

Wilde Benevolent Fund.

No demand has yet been made on this Fund, the interest of which has therefore been accumulating.

Local Honorary Secretaries.

By the death of Dr. Lemon, the position which he, greatly to the interest of the Institution, had held for eighteen years, as Local Honorary Secretary and Treasurer for New Zealand, fell vacant, and was filled by the appointment of Mr. J. K. Logan.

The removal of Mr. Hartley Gisborne to the Far West led to his resignation of the Local Honorary Secretaryship for Canada, and to the appointment of Dr. R. B. Owens, Professor of Electrical Engineering at the McGill University, Montreal, in his place.

Mr. M. G. Simpson's return to England on furlough, and Mr. A. J. Arnot's departure from Melbourne, have caused vacancies in the Indian and Victorian Secretariats respectively. The former position had been filled by the appointment of Mr. T. D. Berrington, of the Indian Government Telegraphs, whilst the latter has not yet been filled. Mr.

Berrington having been invalided home to England at short notice, the Council have appointed his colleague, Mr. A. L. H. Palmer, in his place.

The vacancy in the secretaryship for the Netherlands Indies has led to the rearrangement of the Secretariat, in greater conformity with the present distribution of the membership in the district. Mr. W. Grigor Taylor, a Superintendent of the Eastern Extension Telegraph Company, who has been appointed, is therefore officially designated Local Honorary Secretary and Treasurer for the Straits Settlements and Netherlands Indies; his district, however, includes not only these territories, but also the Federated Malay States and Borneo.

Visit of the Institution to Germany.

By the initial invitation of Director Rathenau, of the Allgemeine Elektricitäts Gesellschaft, and of the Siemens and Halske Aktien-Gesellschaft, of Berlin, and under the guidance of Mr. Alexander Siemens, over 150 members, accompanied by about 30 ladies, visited Berlin at the end of June, breaking the journey at Hanover, where they received a hearty welcome not only from Messrs. Körting Brothers, whose works they visited, but from the City itself, which gave a Banquet in their honour in the evening.

At Berlin, everything that could be done by the German hosts to make the visit useful and enjoyable was done with unstinting hospitality and with characteristic thoroughness. The works were opened freely to the members, and a Ladies' Committee arranged an admirable series of visits and excursions for the ladies of the party.

At the conclusion of the visit some of the members remained to see other works in Berlin, and then returned to England; but the majority proceeded to Dresden, where, by the courteous invitation of the Verband Deutscher Elektrotechniker, they were able to share in the arrangements made by that Society for their Annual Meeting, visits, and excursions.

A large proportion of the party then, by invitation of the Elektricitäts Aktien-Gesellschaft, vormals Schuckert & Co., journeyed to Nürnberg: and next, by the invitation of the Elektricitäts Aktien-Gesellschaft, vormals Lahmeyer, to Frankfort. In both these places the party experienced the same lavish hospitality that had been shown them in Berlin, and finally returned to England after a fortnight's absence, cordially appreciative of the heartiness of the reception that had been accorded them.

Engrossed copies of resolutions conveying the thanks of the Council have been forwarded to the principal firms and individuals who, as hosts, assisted in the reception of the Institution, and to the Verband Deutscher Elektrotechniker.

International Engineering Congress, Glasgow, 1901.

By invitation from the Committee of the Congress, the Institution took charge of the arrangements for the Electrical Section (Section IX) of the International Engineering Congress in Glasgow, in September, 1901. A large number of representative Electrical Engineers, both

from the Continent and the United States, as well as from Great Britain, were present, many of them taking part in the discussions of the Section, as well as in the visits to works. A special number of the Institution Journal has been devoted to the proceedings of the Electrical Section.

The Council has already recorded its thanks to the Glasgow Local Section of the Institution, for its co-operation in these Meetings, which also constituted an Extraordinary General Meeting of the Institution.

Engineering Standards Committee.

The Council, having in view the importance of Standardisation, and having learned that the co-operation of this Institution, as representing electrical engineering, would be acceptable, has cordially consented to assist in the work of the Engineering Standards Committee, of which the constituent bodies had previously been the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Naval Architects, and the Iron and Steel Institute. It has nominated Sir William Preece and Lt.-Col. R. E. Crompton as representatives of the Institution on the Committee.

Special Committees.

The Committee which was appointed to revise the Wiring Rules of the Institution has met frequently during the past twelvemonth, and has so far completed its work that, subject to a few unimportant alterations, the draft of the proposed new rules has been approved by the Council. In the hope of making the rules as generally acceptable as may be, the Committee was so constituted as to represent different interests. By invitation, the Incorporated Municipal Electrical Association sent a delegate, and the rules have been laid before the Committee of the Association. The Fire Insurance experts also gave most valuable assistance, especially in the direction of enabling the Committee to learn the views of the fire offices on all points connected with electrical risks. It is hoped that the new rules may be ready for issue during the present summer, and that they may prove generally acceptable.

A Committee, on which, in addition to consulting and station Engineers, were representatives of the Incorporated Municipal Electrical Association, the Cable Makers' Association, and the Employers' Federation, engaged upon the production of Model General Conditions for electrical contracts, has produced a set of General Conditions which, after approval by Counsel, has been submitted for discussion at an Ordinary General Meeting of the Institution. These, after final revision, will, it is understood, be presented to the Council for acceptance, in the hope that, when adopted as the Form of General Conditions recommended by the Institution, they may by standardisation save much time, labour, and expense to both purchasers and contractors who may adopt them as a whole or in part.

The Committee appointed by the Council to determine whether it could recommend the Council as to the action, if any, to be taken with

a view to assisting the Electrical Industry in connection with the matters dealt with in Mr. Madgen's paper on the Electrical Power Bills for 1900 has met many times during the past twelvemonth, and has received evidence which has been printed *in extenso.* It has also submitted a report and a series of resolutions that have been adopted by the Council. Action has been taken upon the Report, and the Prime Minister has informed the Council that the President of the Board of Trade will, on Thursday, May 29th, receive a deputation with the view to bring fully under the notice of His Majesty's Government the principal disabilities under which, from the Report of the Committee, it appeared that the industry was suffering.

The Factories and Workshops Act, 1901.

In the summer of 1901 the Institution joined in a movement aiming at the exclusion of Electrical Generating Stations, or, failing that, at least of Transformer Stations, from the operation of the Act. It appeared from the correspondence that passed to be impossible for the Home Office to concede this point. There is every reason to hope, however, that the Home Secretary will be prepared to receive from the Council an expression of the views of the Industry upon any regulation that may be found to operate adversely and that is susceptible of modification without jeopardising the interests that the Act was intended to safeguard. The Council is now dealing with this question.

A Conference representing the Industry of Electricity Supply has been held, and has, by Resolution, requested the Institution "to take steps to approach the Home Secretary in order to lay before him the views expressed at this Conference as to the prejudicial effect of the incidence of certain provisions of the Factory and Workshops Act of 1901, on the Industry of Electricity Supply, and to pray him to allow the Institution to confer with him when he is framing Regulations under the Act."

Museum.

As a result of an appeal to Members issued during the past year, many objects of interest have been promised, and the intending donors have, at the request of the Council, consented to retain possession of their donations for the present, with a view to making them over to the Institution as soon as it is in a position to place them on view.

Presentation of Addresses.

Illuminated addresses have been presented through the officially invited delegates of this Institution to the University of Glasgow on the occasion of its ninth Jubilee in 1901, and to the Owens College, Manchester, on that of its Jubilee in March, 1902.

Visit to Northern Italy.

The Council has in hand arrangements for a visit to objects of electrical interest in Northern Italy immediately before Easter in 1903.

INTERNATIONAL TECHNO-LEXICON.

At the request of the Verein Deutscher Ingenieure, the Council has promised such assistance as may be in its power in the editorial work of producing the comprehensive tri-lingual technical dictionary that is being prepared by that Society.

TELEGRAPHIC ADDRESS.

For the convenience of Members the Council has, during the past year, arranged a telegraphic address for the Institution. This address, as already announced, is "VOLTAMPERE, LONDON."

DEATH OF H.I.H. THE EMPRESS FREDERICK AND OF PRESIDENT McKINLEY.

Letters of condolence were addressed through the Home Office to His Majesty the King, and through the German Ambassador to His Imperial Majesty the German Emperor, on the occasion of the lamented death of the Empress Frederick.

Messages were also addressed to the American Ambassador and to the President of the American Institute of Electrical Engineers on the occasion of the assassination of President McKinley.

WORK OF THE INSTITUTION.

Your Council, in passing in review the work of the Session, considers it only right to draw attention to the very great increase in the work of the Institution that has been brought about of late, in part by natural growth, the membership having increased by over 50 per cent. in the past five years, and in part by development along many new lines.

The number of Committees appointed to deal with these developments has increased. There have been 23 Committees during the past Session; and 20 Council Meetings and 92 Committee Meetings have been held in the year now under review—as against, for example, 18 Council and 33 Committee Meetings in 1897. Most of these Committees are well attended by the Members nominated to serve on them. The work of administration also is greatly increased in this direction.

The creation of Local Sections has added to the volume of business, not only directly, by an increase in the correspondence, but indirectly by the necessity to arrange for an adjudication upon papers, and by the greater volume of Editorial work for the Journal. The organisation of visits to places abroad, and the desire of the Council that the Institution should be thoroughly representative of the profession and its interests, have also contributed largely to the increase in work generally. As an indication of this growth, it may be stated that the ordinary correspondence is now over three and a half times as great as it was in 1897.

The Library.

Report of the Secretary.

I have to report that the accessions to the Library during the twelve months, from May 13, 1901, to the date of the Annual General Meeting, numbered 68; nearly all of these were kindly presented by the authors or publishers.

The supply of specifications of electrical patents and that of abridgments of specifications relating to electricity and magnetism are continued by the kindness of H.M. Commissioners of Patents, and the arrangement is still in force whereby the specifications of all electrical patents published during any week are placed on the Library table on the following Monday morning.

The periodicals or printed proceedings of other societies received regularly are, with some additions, the same as last year, as may be seen by the list appended hereto.

The number of visitors to the Library in the twelve months from May 30, 1901, to the date of the Annual General Meeting, has been 463, of whom 25 were non-members.

In closing this Report mention must be made of the impossibility of adding to the Library many books that it is desirable to include owing to the limited space at present available.

WALTER G. McMILLAN, *Secretary.*

APPENDIX TO SECRETARY'S REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

ENGLISH.

Asiatic Society of Bengal, Journal and Proceedings.

Cambridge Philosophical Society.

Engineering Association of New South Wales.

Greenwich Magnetical and Meteorological Observations.

Institute of Patent Agents, Transactions.

Institution of Civil Engineers, Proceedings.

Institution of Mechanical Engineers, Proceedings.

Iron and Steel Institute, Proceedings.

King's College Calendar.

Liverpool Engineering Society, Proceedings.

Municipal Electrical Association, Proceedings.

North of England Institute of Mining and Mechanical Engineers, Transactions.

Physical Society, Proceedings.

Royal Dublin Society, Transactions and Proceedings.

Royal Engineers' Institute, Proceedings.

Royal Institution, Proceedings.
Royal Meteorological Society, Proceedings.
Royal Scottish Society of Arts, Transactions.
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
Surveyors Institution, Transactions.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings.
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Mechanical Engineers, Transactions.
Canadian Society of Civil Engineers, Transactions.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
John Hopkins University, Circulars.
Library Bulletin of Cornell University.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Technology Quarterly.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Electro-Technique Montefiore, Bulletin.
Société Belge d'Electriciens, Bulletin.

DANISH.

Tekniske Forening, Tidsskrift.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Société Française de Physique, Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

ENGLISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Electro Chemist and Metallurgist.
Engineer.
Engineering.
Engineering Times.
English Mechanic and World of Science.
Feilden's Magazine.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
Invention.
Mechanical Engineer.
Nature.
Philosophical Magazine.
Scottish Electrician.

AMERICAN.

American Electrician.
Electrical Review.
Electrical World and Electrical Engineer.
Electricity.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Western Electrician.

AUSTRIAN.

Zeitschrift für Elektrotechnik.

DUTCH.

De Ingenieur.

FRENCH.

Annales Télégraphiques.
L'Éclairage Électrique.
L'Électricien.
L'Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

Ellettricità.
Giornale del Genio Civile.
Il Nuovo Cemento.

SPANISH.

La Ingenieria.

The PRESIDENT: I have now to move, "That the Report of the Council, as just read, be received and adopted, and that it be printed in the Journal of the Proceedings of the Institution."

Mr. W. M. MORDEY: I have great pleasure in seconding that resolution. I suppose this occasion is given as a sort of safety valve for malcontents. The smallness of the meeting is evidence that everybody is thoroughly satisfied with the progress of the Institution, and with the way in which its affairs are managed by the Council. I think this Report is a monument of a very fine year's work. I have much pleasure in seconding the resolution.

The Resolution was put and carried unanimously.

The PRESIDENT: I now have to propose "That the Statement of Accounts and Balance Sheet, of which copies were sent to the Members with the Notice convening the Annual General Meeting, be taken as read." (*Vide* pp. 1346–1355.)

The Resolution was agreed to.

The Institution of

STATEMENT OF RECEIPTS AND ENDING 31st

Dr.

RECEIPTS.

				£	s.	d.
To Annual Subscriptions				5,574	16	8
„ Entrance Fees				616	13	0
„ Publishing Fund				1	1	0
„ Dividends on Investments, viz.—						
Life Compositions	£155	19	9			
General Fund...	139	17	0			
				295	16	9
„ Interest on Cash on deposit				12	16	2
„ Wiring Rules (balance)				18	3	11
				£6,519	7	6

EXPENDITURE FOR THE YEAR DECEMBER, 1901.

Cr.

EXPENDITURE.

				£	s.	d.
By Salaries				1,105	8	4
„ Retiring Allowance...				300	0	0
„ Accountants' Fees ...				15	15	0
„ Attendance, Refreshments, Advance-proofs of Papers, and Petty Expenses connected with Evening Meetings ...				158	6	5
„ Shorthand Reporting				51	9	0
„ Printing, Illustrating, and Advertising the Journal (including Glasgow Congress extra number)	£1,159	12	10			
Less Received for Advertisements	177	0	0			
				982	12	10
„ Compiling and Printing Index to Vols. XXI. to XXX. of the Journal ...				104	15	5
„ Contribution to "Science Abstracts"				800	0	0
„ Binding Cases for Journal				1	8	2
„ Depreciation on Library and Pictures (5 %)				71	2	8
„ „ „ Furniture (5 %)				13	4	10
„ Premiums (1900–1901)				73	11	4
„ Expenses in connection with :—						
Conversazione (irrespective of Printing and Postage)				261	1	8
Visit to Germany, 1901 (balance)				0	16	10
Committee on Electrical Legislation				47	0	5
Glasgow Engineering Congress, 1901 (including Grant to Student Reporters) ...				132	6	9
Annual Dinner, 1901				33	19	6
Local Sections ...				234	18	4
„ Office Rent, Electric Light, and Firing ...				336	0	10
„ Insurance				9	15	0
„ General Printing and Stationery ...				305	8	2
„ General Expenses, viz. :—						
Postage of Journals, Notices of Meetings, and General Postage	600	9	6			
Wreath for H.M. Queen Victoria	11	11	0			
Diploma Cases ...	2	0	0			
Model General Conditions	14	4	10			
Copies of Address to Active-Service Contingent of E.E. (R.E.) V.	4	3	9			
Sundries ...	84	2	2			
				716	11	3
„ Petty Expenses of Local Honorary Secretaries				2	5	7
„ Bank Charges				3	7	2
„ Balance carried to General Fund, being excess of Receipts over Expenditure ...				758	2	0
				£6,519	7	6

LIFE COMPOSI-

Dr.

	£	s.	d.
To Amount (as per last Account)	5,200	0	0
„ Life Compositions since received	15	0	0
	£5,215	0	0

TIONS ACCOUNT.

Cr.

Nominal		£ s. d.	£ s. d.
	By Investments (as per last Account)—		
£400 0 0	New South Wales 4 % Bonds ...	£414 15 0	
318 0 0	Cape of Good Hope 4 % Consolidated Stock	306 0 0	
1,679 19 5	India 3½ % Stock	1,776 5 0	
120 0 0	South-Eastern Railway 5 % Debenture Stock	204 16 6	
355 5 10	Canada 3 % Stock	352 13 6	
289 17 4	Midland Railway 2½ % Consolidated Perpetual Preference Stock	274 11 10	
6 0 0	East India Railway Class "C" Annuity	185 1 9	
87 0 0	Great Eastern Railway 4 % Consolidated Preference Stock ...	130 15 2	
175 0 0	Great Eastern Railway 4 % Debenture Stock	251 5 5	
4 13 6	Great Indian Peninsula Railway "B" Annuity	120 1 6	
143 0 0	Southwark and Vauxhall Water Co. 4 % A. Debenture Stock...	207 17 9	
520 0 0	Staines Reservoirs 3 % Guaranteed Debenture Stock	539 2 3	
200 0 0	Glasgow and South-Western Railway 4 % Preference Stock (1894)	276 5 0	
29 0 0	Madras Railway 5 % Stock ...	44 9 4	
57 0 0	South Indian Railway 4½ % Debenture Stock	84 0 0	
			5,168 0 0
	,, Investments Purchased since last Account—		
30 0 0	Burma Railway Co.'s Stock		30 12 3
			£5,198 12 3
	,, Balance uninvested at this date carried to Balance Sheet		16 7 9
			£5,215 0 0

"BUILDING FUND"

Dr.

				£	s.	d.
To Amount (as per last Account)—						
Investments	£8,212	12	2			
Dividends uninvested	208	18	11			
				8,421	11	1
" Dividends received during 1901				238	4	5
" Subscriptions received during 1901				150	16	0
" Surplus from Vellum Diplomas				5	16	6
" Amount transferred from General Fund in 1901				581	10	9
				£9,397	18	9

ACCOUNT.

Cr.

Nominal			Description				£	s.	d.
			By Investments (as per last Account)—						
£450	0	0	Canada 4 % Reduced Stock ...	£504	0	0			
524	13	0	Canada 3 % Stock	553	10	1			
181	0	0	Great Western Railway 4½ % Debenture Stock	324	17	8			
418	0	0	South-Eastern Railway 3½ % Preference Stock	555	18	9			
370	0	0	London and South-Western Railway Preferred Ordinary Stock ...	510	12	0			
520	0	0	London and South-Western Railway 4 % Consolidated Preference Stock	821	12	0			
190	16	8	India 3½ % Stock	229	9	6			
387	0	0	Great Eastern Railway 4 % Consolidated Preference Stock	575	17	8			
529	12	0	Midland Railway 2½ % Consolidated Perpetual Preference Stock ...	500	0	0			
23	7	5	Great Indian Peninsula Railway "B" Annuity	600	2	6			
80	0	0	London and South-Western Railway 3½ % Preference Stock	99	18	3			
504	0	0	Staines Reservoirs 3 % Guaranteed Debenture Stock	528	5	0			
670	0	0	Glasgow and South-Western Railway 4 % Preference Stock (1894) ...	925	11	9			
75	0	0	Great Eastern Railway 4 % Debenture Stock	107	13	7			
15	0	0	South-Eastern Railway 3 % Preference Stock	15	0	0			
220	0	0	Madras Railway 5 % Stock	340	0	5			
343	0	0	South Indian Railway 4½ % Debenture Stock	509	2	0			
320	0	0	South-Eastern Railway Preferred Ordinary Stock	511	1	0			
							£8,212	12	2
			„ Investments (purchased since last Account)—						
970	0	0	Burma Railway Co.'s Stock...				989	12	9
							£9,202	4	11
			„ Balance, being amount uninvested at this date, carried to Balance Sheet				195	13	10
							£9,397	18	9

"SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

"SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Balance (as per last Account)	53	10	5
„ Dividends received in 1901	69	6	1
	£122	16	6

"DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

"DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Dividends received in 1901	59	10	3
	£59	10	3

"WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,500	0	0
	£1,500	0	0

"WILDE BENEVOLENT

Dr.

	£	s.	d.
To Balance (as per last Account)	21	2	11
„ Dividends received in 1901	43	7	11
	£64	10	10

FUND" CAPITAL ACCOUNT.

Cr.

		£ s. d.
By Investments, viz.—		
£1,500 New South Wales 3½ % Stock	...£1,556 5 9	
500 Cape of Good Hope 3½ % Stock	... 570 13 6	
		2,126 19 3
		£2,126 19 3

FUND" INCOME ACCOUNT.

Cr.

	£ s. d.
By Amounts paid to 1901 Scholars (Messrs. J. D. Griffin and H. A. Skelton)...	50 0 0
„ Balance carried to Balance Sheet	72 16 6
	£122 16 6

SHIP FUND" CAPITAL ACCOUNT.

Cr.

	£ s. d.
By Investment :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998 15 0
„ Balance uninvested carried to Balance Sheet	1 5 0
	£2,000 0 0

SHIP FUND" INCOME ACCOUNT.

Cr.

	£ s. d.
By Amount paid to 1901 Scholar (Mr. C. J. Hopkins)	25 0 0
„ Balance carried to Balance Sheet	34 10 3
	£59 10 3

FUND" CAPITAL ACCOUNT.

Cr.

	£ s. d.
By Investment :—£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493 16 3
„ Balance invested in P.O. Savings Bank	6 3 9
	£1,500 0 0

FUND" INCOME ACCOUNT.

Cr.

	£ s. d.
By Amount invested in P.O. Savings Bank...	62 11 6
„ Balance uninvested carried to Balance Sheet	1 19 4
	£64 10 10

BALANCE SHEET,

Dr.

LIABILITIES.

		£ s. d.
To Sundry Creditors		689 11 8
„ Local Sections—		
Balance due to Hon. Sec. Glasgow Section	£7 7 0	
do. do. do. Manchester Section	24 8 8	
		31 15 8
„ Subscriptions received in advance—		
On Account of 1902	£81 19 0	
„ 1903	5 6 0	
„ 1904	1 4 0	
		88 9 0
„ Suspense Account—Amount of Subscriptions paid in advance of election		7 11 0
„ "Salomons Scholarship Fund"—Balance of Income Account		72 16 6
„ "David Hughes Scholarship" Fund—		
Balance of Capital uninvested	1 5 0	
Balance of Income Account...	34 10 3	
		35 15 3
„ "Wilde Benevolent Fund"—Balance of Income Account uninvested		1 19 4
„ Life Compositions—Balance uninvested		16 7 9
„ Building Fund—Balance uninvested		195 13 10
„ General Fund—		
Balance as per last Account	£5,574 13 4	
Add Further Amount received for Photographs connected with the Swiss Visit of 1899	0 8 0	
Excess of Receipts over Expenditure ...	758 2 0	
	6,333 3 4	
Less Amount transferred to Building Fund ...	581 10 9	
		5,751 12 7

W G. McMILLAN,
Secretary

£6,891 12 7

We have examined the above Balance Sheet and Statements of Account
cates as to the Securities, and in our opinion the Statements are correct
correct view of the state of the affairs of the Institution as shown by its
We hereby certify that all our requirements as Auditors have been com-

ALLEN, BIGGS & CO.,
Chartered Accountants,
38, PARLIAMENT STREET, S.W.

11th April, 1902.

Cr.

ASSETS.

				£	s.	d.
By Cash—						
At Bankers'	470	10	5			
Petty Cash	36	4	4			
				506	14	9
„ Local Sections—						
Balance in hands of Hon Secretary, Dublin Section	£5	7	6			
Do., Newcastle Section...	6	12	11			
Do., Birmingham Section	6	19	0			
				18	19	5
„ Investments, "General Fund"—						
£1,418 8 0 Midland Railway 2½% Consolidated Perpetual Preference Stock	£1,200	0	0			
918 3 2 India 3½ % Stock	973	17	10			
52 13 8 Great Indian Peninsula Railway "B" Annuity	1,239	17	9			
721 0 0 Madras Railway 5% Stock	1,114	14	0			
				4,528	9	7
„ Sundry Debtors				122	13	11
„ National Telephone Co. Deposit...				0	10	0
„ Furniture—						
As per last Balance Sheet	242	0	6			
Additions during 1901	22	15	6			
	£264	16	0			
Less Depreciation (5 %)	13	4	10			
				251	11	2
„ Books, Pictures, &c., other than the Ronalds Library—						
As per last Balance Sheet	1,397	13	5			
Books and Periodicals added during 1901 ...	24	19	0			
	£1,422	12	5			
Less Depreciation (5 %)	71	2	8			
				1,351	9	9
„ Stock of Institution Journals, Ronalds Library Catalogues, &c.—						
As per last Balance Sheet	242	17	9			
Less Amount realised during 1901	152	8	3			
				90	9	6
„ Stock of "Cooke Manuscripts"				18	5	2
„ Stock of Vellum Diploma Forms				2	9	4
				£6,891	12	7

with the Books and Vouchers of the Institution, and the Bankers' Certifi-
and the Balance Sheet is properly drawn up so as to exhibit a true and
books. The Securities have been included in the Accounts at cost price.
plied with.

F. C. DANVERS } *Honorary Auditors.*
E. GARCKE }

The PRESIDENT: I have now to propose, "That the Statement of Accounts and Balance Sheet for the year ending December 31st, 1901, as presented, be received and adopted."

Mr. E. TREMLETT CARTER: I have much pleasure in seconding that resolution. I am sure that, as an ordinary Member of the Institution, I speak for my fellows when I observe that these accounts show a very flourishing and satisfactory condition in the Institution of Electrical Engineers at the present time. The Report refers to the increase in the work of the Institution; it states that the membership has increased by over 50 per cent. in the past five years, and also observes that the work has increased in part by the development along many new lines. We know that this involves great expenditure, and it is highly satisfactory that notwithstanding this much greater expenditure and increased activity we are able to show a balance on the right side, and to add something to that very important fund, the Building Fund. I cannot sit down without saying how glad I am that it has at last reached five figures, and I hope very soon the first figure will be a five. I have great pleasure in seconding the resolution.

Mr. W. R. RAWLINGS: Before the resolution is put to the meeting, I wish to say that the absence of members shows the confidence which every member has in the Council, and also in the accounts submitted. I should like to point out that while there is an increase in the receipts of £254, there is also a difference in the balance carried forward between this year and last year of £791. Those two items added together make a total of £1,046, which practically represents the difference between this year's and last year's accounts. I do not suggest for a moment that economy has not been studied throughout, and carefully studied. I remember that last year you had the Paris Exhibition expenses and also the expenses of the students who were sent there, and this year you had the compensating item with reference to Glasgow. But what I wish to dwell upon is this. I take it that this Institution, with its growing membership, its growing receipts, and also its increased expenditure, is carrying forward now a balance of only £758, and I venture to suggest, if we had our own building to maintain that sum would not be of any practical service to us whatever. It behoves the Council to look into this matter somewhat carefully, otherwise I think we shall not in future be in a comfortable financial position. Fortunately the Institution of Civil Engineers and the Society of Arts have come to our rescue, and have lent us buildings in which to hold our meetings, free of all charge. If they had not done so, I am afraid that any expenditure we might have incurred upon a building of our own would have left us with practically no balance at all. Something should be done in order that the accounts may show a larger balance than they do this year.

The PRESIDENT: I am sure it is extremely gratifying to the Council to receive these warm commendations from the members of the Institution. I need not say that the question of expense is constantly receiving attention at the hands of both the Council and the Finance Committee, and the Council would not think of incurring any heavy expenditure unless they saw their way to meet it. Members may rely upon it that the Council have the matter constantly before them, and

that no expense will be incurred unless the funds of the Institution are such as will meet it.

The resolution for the reception and adoption of the accounts and balance sheet was then put and carried unanimously.

Colonel H. C. L. HOLDEN: I rise to propose a vote of thanks to the Institution of Civil Engineers in the following terms:—"That the Members of the Institution of Electrical Engineers appreciate highly the privilege of holding their meetings in the rooms of the Institution of Civil Engineers, and hereby tender their hearty thanks to the President, Council, and Members of that Institution for the continuance of their hospitality during the past Session."

Mr. C. W. S. CRAWLEY: I have much pleasure in seconding that.

The PRESIDENT: I have also much pleasure in putting that resolution to the meeting. The Institution is much obliged to the Institution of Civil Engineers. They are a constant help to us in affording us the convenience and accommodation of their beautiful rooms.

The resolution was put, and carried unanimously.

Mr. J. SWINBURNE: I have much pleasure in proposing a somewhat similar resolution of thanks to the Society of Arts, who allow us to use their rooms as we have done to-night. We are so accustomed to the hospitality of the Institution of Civil Engineers and the Society of Arts, that those Institutions perhaps hardly realise what a benefit their hospitality is to us. At present we are a homeless Society, although it is to be very seriously hoped that we shall not be homeless for long; but in the meantime we owe a great deal to these Societies for their hospitality. I therefore propose, "That the Members of the Institution of Electrical Engineers hereby express their cordial thanks to the Society of Arts for the great privilege of holding their evening meetings in May in the rooms of that Society."

Mr. A. T. TURNEY: I have much pleasure in seconding that resolution.

The resolution was put, and carried unanimously.

Mr. ALEXANDER SIEMENS: We are indebted to a number of gentlemen who, in foreign countries, have undertaken the duties of Local Honorary Secretaries and Treasurers of the Society. We have all heard with great pleasure from the Report how the Institution is increasing, and how Local Sections have been formed which hold their own Meetings and at which papers are read. All that throws more work not only on our own Secretary, but also on the Honorary Secretaries who have so kindly volunteered their services. I have great pleasure, therefore, in proposing, "That the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year."

Mr. A. A. CAMPBELL SWINTON: I have much pleasure in seconding that resolution.

The PRESIDENT: We cannot thank these gentlemen too much for the services they render to us, which are perfectly gratuitous on their part. We are very much indebted to them. They advocate our interests all over the world.

The resolution was put, and carried unanimously.

Mr. J. E. Kingsbury: I have much pleasure in proposing, "That the thanks of this Institution be accorded to Professor Ayrton for his kind services as Honorary Treasurer during the past twelve months." I do not think that the members generally can have any idea of how well and how thoroughly those services are carried out. Professor Ayrton brings to Finance a scientific training, and from my experience on the Finance Committee I am perfectly well satisfied there is nothing which is so helpful to a financier as a scientific training. At the same time I think that whilst he watches carefully over the purse strings, the members should clearly understand how much they are indebted to him for the care which he bestows and for the attention which he gives, because you must remember the care is always exercised for the benefit of the Institution, whether it be in the holding of money or in the spending of it. I can add to this resolution the hope, which I am sure will be accorded generally, that Professor Ayrton may long have health and strength to carry out those duties so well and so thoroughly as he does.

Mr. S. Joyce: I have much pleasure in seconding that resolution. May I also add that I think I am voicing the opinions of most members present, and those who are absent, when I say that I hope the arduous duties that the treasurership imposes upon Professor Ayrton will not tend to keep him away from the meetings so much as during the past session. I think most of us were very glad indeed when he appeared amongst us for the first time quite recently, and I am quite sure his presence will add considerably to the interest and value of the meetings. I have much pleasure in seconding the resolution.

The President: I have much pleasure in placing the resolution before the meeting, and I am sure it will be carried with acclamation. We all know that Professor Ayrton is devoted to his work, and we also know that he keeps a very tight hand indeed over the purse-strings. We are very much indebted to him for it, because we are all inclined, when we get an application which specially appeals to us, to accord it consideration if we can, and if it were not that we have to refer expenditure demands to the treasurer, I think we should perhaps be inclined to spend more money than we do.

The resolution was then put, and carried with acclamation.

Professor W. E. Ayrton, in acknowledging the vote, said: The tightness that the President has referred to has been exercised by me for several years past because I had a very definite object in view. I have been most anxious by economy, by pressure on the Council and the Finance Committee, to bring the Building Fund up to the sum which at a recent general meeting the President announced to you it had reached, viz., £10,000. I have regarded this for some years past as a sort of goal that I should aim at, and having reached that goal I felt that my services as treasurer were not perhaps so much needed by this Institution. The goal of £10,000 seemed to me very important to arrive at, because I felt that when we had obtained that sum we should be in a position to appeal generally, not merely to our members of all classes, but to the electrical profession of the country, the electrical industry generally, for subscriptions to enable us to obtain a building worthy of this

Institution. In many respects this Institution has progressed in a marvellous way. I remember quite well its beginning thirty years ago, when there was considerable doubt as to whether any such Institution, even in a small way (the Society of Telegraph Engineers), could possibly succeed. A few years later, in 1878–9, the Society was hopelessly in debt, and there seemed to be considerable doubt as to whether it would be ever carried on. It is an open secret that it only was carried on by some of us putting our hands in our pockets and subscribing for a loan of several hundred pounds in order to pay the debts the Society was then labouring under. What is the condition of the Institution now? You have not merely the Building Fund, which has reached, I am happy to say, £10,000, it having increased by £1,600 since December, 1900, when the fund amounted to £8,400; but you have the general fund of several thousand pounds, and you have the life compositions, invested, of £5,000; in fact, the finances are, as has been said by Mr. Tremlett Carter, in a most satisfactory condition. But what is our condition now as compared with our condition thirty years ago? In one respect it is exactly the same. We were the guests then of the Institution of Civil Engineers; we are the guests to-day of the Institution of Civil Engineers; and deeply grateful as we all are to our hosts, the Civil Engineers and the Society of Arts, it seems to me that we have really intruded too long on their hospitality, and that it is not becoming for an Institution like our own, an Institution which represents I may say one of the most important professions to-day in this country—certainly the most rapidly advancing profession—it is not dignified that we should not have any home in which to meet. I therefore take this opportunity of asking, of entreating, of imploring the profession to come forward with liberal subscriptions and contributions so that we may be enabled to deal with some building such as we have inspected year after year, but have been unable to take for want of money. If the new President succeeds in accomplishing this result during the tenure of his office, by getting subscriptions and inducing the profession and industry generally to contribute to the Building Fund, he will make his presidentship more memorable even than he must certainly make it by his ability, his industry, and position.

Mr. Alexander Siemens: May I say one word more with regard to Professor Ayrton. The seconder of the resolution of thanks made a remark which seemed to indicate that Professor Ayrton had absented himself very often from the general meetings without cause; but we know, at least the Council know, that his absence was owing to a serious illness. I am sure we are all very glad to see Professor Ayrton amongst us again. I think it is only right, as these speeches go on the Minutes, that this explanation of his absence should be given.

Mr. H. E. Harrison: I have much pleasure in proposing a vote of thanks to our Honorary Auditors. The members who read the accounts published in our Journal will see that the post of the auditor is by no means a sinecure, and that these gentlemen devote a very great deal of time and trouble to the interests of the Institution. I need, therefore, only formally propose "That the thanks of this Institution be given to

Mr. F. C. Danvers and Mr. E. Garcke for their kind services as Honorary Auditors during the past year."

Mr. R. W. HUGHMAN: I have much pleasure in seconding the resolution. When we consider how busy these gentlemen are, Mr. Garcke especially, I am sure you will agree that they deserve our most cordial thanks for giving the large amount of detailed attention that must be necessary to audit these accounts effectively. The accounts are now very much bigger than they used to be; and they pass as a matter of course, whereas once upon a time there used to be stormy debates upon them.

The resolution was put, and carried unanimously.

Mr. R. PERCY SELLON: I have much pleasure in moving a vote of thanks to our Honorary Solicitors. The report mentions the regret we have felt at the loss of Mr. George Bristow as one of our members, and not less I am sure do we deplore his loss as the member of that firm of Honorary Solicitors who devoted himself more especially to the work of our Institution. That work has been very kindly and efficiently carried on by his colleagues, and our thanks are due to them for their services. I have, therefore, much pleasure in moving: "That the best thanks of the Institution be tendered to Messrs. Wilson, Bristows, and Carpmael for their kind services as Honorary Solicitors during the past year."

Mr. BERNARD DRAKE: I have much pleasure in seconding that resolution.

The resolution was put, and carried unanimously.

The PRESIDENT: I have to announce, gentlemen, that the candidates balloted for on the two lists are certified as duly elected.

Member:

Herbert John Somerset.

Associate Members:

Albert Edward Bulmer.
(Hon.) Geoffrey Lawrence Parsons.
Frederick Pooley.
Frank Hugh Preece.
George Bolland Winkfield.

Associates:

H. Douglas Carter.
John Ferguson.
Sorab Frommurze.
William John Greer.
Oswald Charles Jones.
John Percival Vissing Madsen.
Robert Edward Moyniham.
Evers Musgrave.
Patrick Alfred Paris.
Cades Alfred Middleton Smith.
William Anderson Still.
Max James Eccles Tilney.
George Addison Williams.
James Young.

Students:

Capel Colquhoun Berger.	Richmond Henry Mace.
Henry Braithwaite.	Donald MacLean.
William Leighton Chubb.	Alfred Thomas Morris.
Bryan Pellew Davies.	Norman Scott Percival.
Jose Maria de Artola.	Eustace Blackburne Ritson.
Leonard Gillitt.	Elias Zaragoza y Roxas.
T. Craythorne Hall.	Edwin Ross Rudge.
Leslie Geo. Frederick Harris.	Douglas Mansel Strode.
Egerton Baird Hunter.	Herbert William Swann.
Edward Karam.	Alban Cecil Whish.
Claude Neville Macdermott.	Arthur Reginald Wood.

I have also to announce that no nominees having been received other than those announced at the general meeting on April 24th, the Council's nominees are, in accordance with Number 45 of the Articles of Association, duly elected to their respective offices, and the following constitute the Council and the Honorary Officers for the twelve months 1902–3:—

President.

JAMES SWINBURNE.

The Past Presidents.

The Chairmen of Local Sections.

Vice-Presidents.

Major P. CARDEW, R.E.	JOHN GAVEY.
S. Z. DE FERRANTI.	Professor O. LODGE. F.R.S.

Members of Council.

Sir J. WOLFE BARRY, K.C.B., F.R.S.	Lt.-Col. H. C. L. HOLDEN, R.A., F.R.S.
H. H. CUNYNGHAME, C.B.	J. E. KINGSBURY.
S. DOBSON.	The Hon. C. A. PARSONS, F.R.S.
B. DRAKE.	W. H. PATCHELL.
R. KAYE GRAY.	J. H. RIDER.
H. E. HARRISON, B.Sc.	MARK ROBINSON.
HUGO HIRST.	C. P. SPARKS.

A. A. CAMPBELL SWINTON.

Associate Members of Council.

W. R. COOPER, M.A., B.Sc.	W. DUDDELL.

SYDNEY MORSE.

Honorary Auditors.

FREDERICK C. DANVERS.	SIDNEY SHARP.

Honorary Treasurer.

Professor W. E. AYRTON, F.R.S., Past President.

Honorary Solicitors.

Messrs. WILSON BRISTOWS and CARPMAEL.

The PRESIDENT: Gentlemen, before I quit this Chair I wish to tender to my colleagues, the members of the Council, and all the members of the Institution, my very hearty thanks for the ready and cordial assistance they have rendered me during my term of office. I have received at their hands the most ready help at all times, and had it not been for that ready assistance it would have been impossible for me to discharge the duties that have devolved upon me. I venture to hope that the session will not have proved unfruitful. In some sense I look upon it that the session will have left its mark in the annals of the Institution, for I do not think that at any period in the existence of the Institution has it become more fully representative of the profession or allied itself more closely with the interests and the advancement of electrical engineering than during the session now about to terminate. I can only hope that that which has been done will prove acceptable to the general body of members. I feel satisfied that the course which has been pursued will be to the interest not only of the Institution but of the profession. It is quite true that this Institution is a scientific Institution, but, gentlemen, I cannot see why a scientific institution should not also be representative of that profession which springs out of the science which is the basis of the Institution. We all of us have to remember that the position of the electrical engineering industry, if we may so refer to it, is at the present moment very different to what it was some twenty or twenty-five years back. The birth of the dynamo has made possible a very large industry, and that industry demands some representation; it must have some one to fight its battles; and it appears to me there is no body and no institution in the kingdom which is so capable as, or which stands in a more sound position for dealing with matters which affect its interest than, this Institution.

At the same time it is quite clear that the Institution cannot afford to sink its prestige in dealing with every little incident which arises that may indirectly touch the profession or the industry. To do so will be to lose its power. Therefore, although the Institution ought to be regarded as the representative institution in this respect, it is desirable that its power and its prestige should be reserved for those important occasions which call for its powerful aid.

Before I invite my successor to take this Chair, I also desire to tender my hearty thanks to Mr. McMillan for his ever-ready services, and for the assistance he has rendered me. No one can be more devoted to his duty than Mr. McMillan. His heart and soul are always in his work, and his tact is always present. He entirely neglects his own comforts in the interests of the Institution. Now, gentlemen, I have but one other duty to perform, and that is to invite Mr. James Swinburne to occupy this Chair. Mr. Swinburne will require no introduction on my part. He has gained for himself a world-wide reputation, and he is so well-known to all of you that no words from me can be necessary on his behalf.

[The Chair was then vacated by Mr. Langdon and taken, amid applause, by Mr. James Swinburne.]

The PRESIDENT (Mr. Swinburne): There is in many cases a touch

of sadness about the election of a new President. Nothing is known of the future work of the new President ; he is on his trial, and will be judged, I hope in this case leniently, at the end of his time. But the election of a new President means the loss of the services of an old President, and in this case the loss of his services is appreciated thoroughly by the whole Society, and especially by those who have been associated with him on the Council. I will not trench on what Mr. Siemens will state very much better than it is possible for me to say, but I will now call upon Mr. Siemens to propose a vote of thanks to the President we have lost.

Mr. ALEXANDER SIEMENS : I think it is extremely unkind of you to handicap me in that way. The words which Mr. Langdon spoke to us before leaving the Chair really have paved the way to expressing to him the great thanks we owe to him for the way in which he has conducted the affairs of the Institution. We have passed many congratulations and votes of thanks to-night to the various bodies and officials connected with the Institution, but, after all, it is the President who has to bear the brunt of the work. As Mr. Langdon pointed out, the Institution has done much work during the past year, different to what it has ever done before. I would remind you that the revision of the Wiring Rules has at last been pushed through. Then we have had several points under consideration in connection with Electrical Legislation ; we have pushed forward the Building Fund during the year, and all those things have been passed upon the initiative and guidance of Mr. Langdon, who has acted as a practical man would do. He is mostly concerned with the practical application of electricity, and he has guided the Institution in that direction. He has considered that not merely the scientific teaching of electricity should be the subject of the Institution's labours, but its application in every possible way. For his labours in those directions our special thanks are due to Mr. Langdon for having given this new direction to the aims of the Institution. I have, therefore, great pleasure in moving : "That the most cordial thanks of the Institution of Electrical Engineers be and hereby are tendered to Mr. Langdon for the very able manner in which he has conducted the affairs of the Institution during his year of office as President ; for the unfailing geniality and tact which he has throughout displayed ; for his regular attendance at meetings notwithstanding his residence in the Midlands ; and for the constant devotion that he has shown to the duties of his office."

Sir HENRY MANCE : I have much pleasure in seconding that resolution. I think we must all admit that Mr. Langdon has performed the duties of his office with dignity. Speaking as a member of Council, and meeting him frequently at committees, I may say that he has conducted the business with tact and with universal courtesy. Any one reading the Report cannot fail to appreciate the enormous increase of work that has taken place in transacting the business of the Institution during the last few years, and it must have been more difficult for the President to perform his duties in consequence of the distance that he lives away from London. I am very sorry there are not more members here to-night, and that there has been a departure in the

last year or two from the old procedure of thanking the retiring President when there is a certainty of a full meeting; but I am quite sure that, few as we are, we represent fully the feeling of the general body of members, and that we heartily and sincerely thank Mr. Langdon for the way in which he has carried on the duties and furthered the interests of the Institution during the past year.

The resolution was put, and carried by acclamation.

Mr. LANGDON: Gentlemen, I thank you very sincerely for the very kind manner in which you have received this resolution. I tender my very hearty thanks to the proposer and seconder for the graceful language in which they have couched it. It is to me a great gratification that I have been able to deal with the duties which you so generously entrusted to me in a manner which should have merited your approbation. It is quite true that I have been somewhat inconveniently situated for the performance of those duties which so frequently necessitated my presence in London, but the ready and hearty assistance I have received from my colleagues around me has lightened my work and amply repaid me for any inconvenience that may have been incurred by me in consequence. It is quite true that the work of the Institution has largely increased. No one except those who are in intimate association with the Secretary can have any idea of the extent of correspondence, and the many arrangements that are necessary to deal with it in a satisfactory manner. I am extremely obliged to you, gentlemen, and highly appreciate the resolution you have placed on the Records of the Institution.

The PRESIDENT: The session is now adjourned until November next.

OBITUARY NOTICES.

WILFRED DANIEL BAILEY was the fourth son of Mr. John Bailey, who began his connection with Messrs. Silver & Co. in 1848, and, as Resident Manager of the Silvertown Works for over forty years, has been intimately associated with their growth from very small beginnings to their present vast manufacturing output. Young Wilfred D. Bailey, after leaving school, served five years' apprenticeship in the engineering shops at Silvertown, and qualified himself in the various branches of engineering. In 1888 he went out to Buenos Ayres as assistant at the India Rubber Company's branch in that town. The post afforded him scope for turning his engineering education to account, and also gave him an opportunity for acquiring a thorough knowledge of business. He served seven years in this position, and then, in 1895, set up on his own account in conjunction with Mr. L. Walker as Electrical and General Engineers, under the style of Bailey, Walker & Co. His early engineering training at Silvertown, combined with the business experience gained in the Company's agency, were now of great service to him, and the firm soon acquired a leading position in its particular branch of industry. There was every prospect of a highly successful future when, following shortly after his partner's death, Mr. Bailey himself contracted typhoid fever, and after three weeks' illness, though considered convalescent, suffered a relapse and died.

At the time of his death at Buenos Ayres on the 1st of December, 1901, Mr. Bailey had only reached the age of thirty-four, and the popularity of his genial and kindly character was attested by the number of friends—close upon two hundred—who assembled at his funeral, and by whom his loss will be deeply felt. The deceased leaves a widow, but there was no issue by the marriage.

Mr. Bailey was elected an Associate of the Institution on the 12th of January, 1888, and was transferred to the class of Members on the 28th of May, 1896.

ALFRED S. BOLTON, the well-known copper-wire maker, was born in 1827, near Birmingham, and died last December at the ripe age of 76. He was educated at University College, London. His father's health compelled him to take charge of the business of Thomas Bolton & Sons very early. In 1852 the wire-drawing department was removed to Oakamoor, where at first only fifty hands were employed, but latterly between six and seven hundred were on the books. His energy secured virtually the monopoly of submarine cable conductor making. All the early cables were made with Bolton's copper. The wire supplied for the Atlantic cable had a conductivity of only 40 per cent. of pure copper, but, inspired by Lord Kelvin, Mr. Bolton soon remedied this defect, and latterly copper of over 100 per cent. of conductivity was turned out from Oakamoor. In addition to the works at Birmingham and Oakamoor, there are works at Froghall, large smelting, refining, and rolling mills at Widnes, and engineering works

at St. Helens. Altogether they employ from 1,500 to 2,000 hands. Mr. Bolton was full of enterprise. He joined many electrical companies, and was closely allied with the British Aluminium Company, whose works are at Larne, Foyers, and Milton, near Stoke. He had great faith in the future of aluminium. He was of an enquiring and inventive disposition. All the works are full of ingenious contrivances emanating from his resourceful mind. He was an ardent sportsman and a keen shot. He took a deep interest in political, county, municipal, educational, and technical matters, and his absence will be severely felt in his own neighbourhood. His face and presence will be much missed by a large number of earnest electrical friends.

Mr. Bolton was elected a Member of the Institution on the 11th of March, 1886. W. H. P.

GEORGE LEDGARD BRISTOW, who died at his residence at Haslemere on the 19th of September, 1901, was a member of the firm of Wilson, Bristows and Carpmael, of Copthall Buildings, the Honorary Solicitors to the Institution. He was admitted a solicitor in 1851, and from the earliest days took a keen personal interest in the affairs of the Institution, his firm having been annually elected Honorary Solicitors since 1873. His genial personality was at one time better known to the members than it has been of late, when advancing years rendered it less easy for him to attend evening meetings. But, even to the last, he was always ready to give the closest and most careful attention to all the business of the Institution requiring legal advice or assistance, and the Institution has, in him, lost a good friend and a wise counsellor who, often at personal inconvenience, rendered constant and valuable assistance during a long term of nearly thirty years.

Mr. Bristow was elected a Member of the Institution, then the Society of Telegraph Engineers, on the 22nd of January, 1873.

WALTER THOMAS GOOLDEN, one of the pioneers of dynamo building and electrical instrument making, died on the 16th of September, 1901, at the age of 53, just when a man of his temperament, by accumulation of experience, becomes fitted for his best work. He was the antithesis of the pushing business man for whom integrity is a crotchet and intellect a fad, who counts all time lost until he begins to make his mark in his narrow line of life. Member of Magdalen College, Scholar of Merton College, Oxford, taking first class honours in Science in 1871, Master at Tonbridge School from 1876 to 1883, he sought, in 1884, to turn to the more active employment of his scientific tastes and went into partnership for a short time with Mr. H. Edmunds, in those imaginative days when electrical engineering was a three-year-old profession. He had a singularly exact and clear, but totally unpedantic, knowledge of electrical science. From 1884 to 1887 his business lay in the anxious and no doubt distasteful cares of the finance and order-getting for the young firm of Goolden and Trotter, while most of the interesting work was carried on at the works at Halifax. In 1887 the firm became Goolden & Co., Mr. Ll. B. Atkinson going into partnership, and the works were concentrated in London.

Soon after the amalgamation with Easton and Anderson of Erith, the instrument-making business, now that of Evershed and Vignoles, was left in London, Mr. Goolden went to reside at Newcastle, to work up the electrical coal-cutting business, and after the reconstruction of the Erith firm, remained there in consulting practice, and his last work was in connection with the Steljes Typewriting Telegraph.

From the point of view of a successful business man (as some men measure success) Mr. Goolden was handicapped by want of commercial training, and by the perfection of his honesty, and there are some who would have counted the transparent frankness and warmheartedness of his nature as a disadvantage. But such views depend upon what is meant by success. If one weakness may be admitted, it was that he could hardly believe that those with whom he had dealings were not all as upright and of as good faith as himself.

His keenness, whether in getting a contract in close competition, or in breaking a record in carrying out some of the stiff conditions of Admiralty dynamo specifications, his patience, and his good humour will always be remembered by his partners and their staff.

An old Tonbridge friend of his writes: " Beyond his attainments in Natural Science, he was a mathematician of no common order, and a man of wide sympathies. He was often to be found on bright winter evenings in the School Observatory with a small band of observers, whom he had inspired with his own love for astronomy. He was also a good musician, and his beautiful tenor voice is still remembered by members of the Tonbridge Choral Society of those days. He was a man of singular amiability and straightforwardness of character, and was much liked and respected both by masters and by boys."

He was elected an Associate on the 23rd of April, 1885, and was transferred to the class of Members on the 10th of January, 1889. He was an Associate Member of the Council in 1888, and was a full Member of the Council from 1893 to 1895.

JOSEPH HOWE, whose life has been devoted to telegraphy, commenced his career in the service of the Telegraph Construction and Maintenance Company. After three years he joined the Anglo-American Telegraph Company, and then, three years later, in 1873, the Western, or, as it was then called, the Brazilian Submarine Telegraph Company. From 1873 to 1894 he acted as superintendent for this company; he was then transferred for four years to Pernambuco, returning in 1898 to Madeira, where he remained until, in failing health, he left to retire on his pension, taking passage homeward in the *Dunvegan Castle*, in December, 1901. He was, however, destined never again to see his native country, for he died at sea on the 21st of December.

He was elected an Associate of the Institution on the 13th of May, 1874, and transferred to the class of Members on the 10th of March, 1881.

JOSEPH SLATER LEWIS, whose death occurred at his residence, Clifford Lodge, Norwood, on the 27th of July, 1901, in his 50th year, was

a man with many friends, and concerning whom even his enemies spoke well. He was vigorous, intelligent, genial, and straightforward. Mr. Lewis came to reside in London only a few months before the date of his death, to take up the position of Director of the Brush Electrical Engineering Company. He was also elected a Director of the Swansea Tramways Company, and of the Merthyr Electric Light and Traction Company. The sphere of his activity was increasing rapidly when the disease (Bright's) which, unknown to him, had been sapping his vitality, claimed him as its victim.

Mr. Lewis was known to the electrical world principally as the constructor of the Helsby Cable Works and manager of the Salford Rolling Mills (P. R. Jackson & Co.), also as the author of "The Commercial Organisation of Factories," a monument to its author and a boon to all who desire to organise their manufacture on sound commercial lines.

Mr. Lewis's activity was not confined to electrical engineering. Whilst living at Helsby he was elected a member of the first Cheshire County Council for the Frodsham Division, and as Chairman of the Weights and Measures Committee he introduced many valuable reforms. He was an Associate Member of the Institution of Civil Engineers, a Member of the Institution of Mechanical Engineers and of the Iron and Steel Institute, and a Fellow of the Royal Society of Edinburgh.

He was elected an Associate of this Institution on the 14th of February, 1884, and was transferred to the class of Members on the 9th of February, 1898. He also served, in 1900, as a Member of the first Committee of the then newly-formed Manchester Local Section.

J. S. R.

CHARLES W. LUNDY, who died at Halifax, Nova Scotia, aged 68, on the 16th of December, 1901, was born in England, and was, in 1865, engaged on the S.S. *Great Eastern* during the laying of the Transatlantic Cable. After its completion he was appointed Superintendent at Heart's Content, Newfoundland. After a period of service here, he joined the Eastern Telegraph Company, and, whilst with them, was stationed for three years as their superintendent at Madras. Then, in 1875, Mr. Lundy became Superintendent for the Direct United States Cable Company at Tor Bay, Nova Scotia, transferring to Halifax when, in 1890, the cable was continued to that city.

During one of his furloughs to Europe (in 1899) he joined in the Institution Visit to Switzerland. He was elected an Associate on the 9th of December, 1874, and was transferred to the class of Members on the 13th of January, 1875.

JOHN NEALE, aged 68, died at his residence, Wychdon Villa Hixon, near Stafford, on the 18th of December, 1901, after a brief illness, and was interred at Hixon Parish Church on December 21st.

Mr. Neale was born in London, educated at Trinity School, Bow, and joined the services of the Electric and International Telegraph Company in 1851 at the Strand office; was transferred to Stafford in

1852, Manchester 1853, and Birmingham 1854. In 1859 he was appointed Inspector in charge of the North Staffordshire and London and North-Western lines in the Midland Counties. In 1870, on the transfer of the telegraphs to the Government, he was appointed Telegraph Superintendent and Electrical Engineer to the North Staffordshire Railway Company, which position he held up to the time of his death. In 1873 he patented the acoustic Single Needle dial, which is now used by the Post Office and railways, and a single wire block instrument which is now in use on the North Staffordshire Railway; also a recording block instrument for permissive block use, showing the number of trains actually in the section, and a rail treadle so that the trains can announce their approach at level crossings automatically.

Mr. Neale also acted as Honorary Secretary to the Conference of Railway Telegraph Engineers and Superintendents at their half-yearly meetings.

He was elected a Member of the Institution on the 28th of November, 1877.

A. F R

REFERENCES TO PAPERS READ BEFORE LOCAL SECTIONS OF THE INSTITUTION, AND PUBLISHED, IN FULL OR IN ABSTRACT, IN THE TECHNICAL PRESS, BUT NOT YET ORDERED TO BE PRINTED IN THE JOURNAL OF THE INSTITUTION.

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"NOTES ON INDUCTIVE CIRCUITS," by W. BREW, Associate Member.
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"RAILWAY BLOCKS AND TELEGRAPHS: RECENT PRACTICE," by A. T. KINSEY, Associate.
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"CONSUMERS' INSTALLATIONS," by M. RUDDLE, Member.
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GLASGOW LOCAL SECTION.

"NOTE ON A NEW ELECTRO-MAGNET FOR MAGNETO-OPTIC WORK," by Prof. ANDREW GRAY, F.R.S., Member.
Electrician, Vol. **48**, p. 848, March 21, 1902.
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MANCHESTER LOCAL SECTION.

"LARGE GAS ENGINES FOR DRIVING ELECTRIC GENERATORS," by A. R. BELLAMY, Member.
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"The TREATMENT AND USE OF AIR-CORE CABLES," by G. E. FLETCHER, Member.
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"ELECTRIC PROBLEMS OF RAILWAYS," by J. SWINBURNE, Member.
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Electrical Review, Vol. **50**, p. 123, January 24, 1902.
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NEWCASTLE LOCAL SECTION.

"ELECTRICAL POWER SUPPLY ON THE N.E. COAST, by C. S. VESEY BROWN, Member.

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"ELECTRICAL LEGISLATION AND FINANCE," by H. W. HANDCOCK, Member.

Electrical Engineer, Vol. **29**, Supplement of February 28, 1902 (p. 5).

"MAINS DEPARTMENT OF A DIRECT-CURRENT SUPPLY STATION," by J. F. MOORE.

Electrical Engineer, Vol. **29**, p. 518, April 11, 1902.

"THE DISTRIBUTION OF FLUX IN LARGE ELECTRO-MAGNETS," by W. M. THORNTON, M.Sc., Member.

Electrical Engineer, Vol. **29**, pp. 523, 555, and 590, April 11, April 18, and April 25, 1902, and Supplement of March 9, 1902 (p. 7).

Electrician, Vol. **49**, pp. 229 and 303, May 30 and June 13, 1902.

NOTE.

The Institution is indebted to the Editors of the *Electrical Engineer*, *Electrician*, and *Scottish Electrician* for the use of some of the blocks employed in this volume of the Journal.

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[P] signifies that the reference against which it is placed indicates the general title or subject of a Paper, read either in London or at a Local Section, or published as an Original Communication.

[*p*] signifies that the reference is to a subject incidentally introduced into a paper, and not necessarily indicated by the title.

[D] signifies that the reference is to remarks made in a Discussion upon a paper, of which the general title or subject is quoted.

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[Glas. Cong.] signifies that the paper referred to was read at the International Engineering Congress, Glasgow, 1901.

[Birm. L.S.] signifies that the paper referred to was read at a meeting of the Birmingham Local Section.

[Cal. L.S.]	do.	do.	do.	of the Calcutta Local Section.
[Cape L.S.]	do.	do.	do.	of the Cape Town Local Section.
[Dub. L.S.]	do.	do.	do.	of the Dublin Local Section.
[Glas. L.S.]	do.	do.	do.	of the Glasgow Local Section.
[Man. L.S.]	do.	do.	do.	of the Manchester Local Section.
[Newc. L.S.]	do.	do.	do.	of the Newcastle Local Section.

Note.—The lists of speakers in the Discussion upon any Paper are no longer quoted in the Index. They are, however, given in the Table of Contents at the beginning of the volume, and are readily found by ascertaining the page in the Journal from the entry in the Alphabetical Index, and then referring back to the corresponding portion of the Table of Contents, which is arranged serially in the order of the pages of the Journal.

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